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FEASIBILITY OF FABRIC FILTER AS GAS - SOLID CONTACTOR TO CONTROL GASEOUS POLLUTANTS

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OWENS - CORNING FIBERGLAS CORPORATION
GRANVILLE, OHIO

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Sodium carbonates
Manganese oxides

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FINAL REPORT

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FOREWORD

This report covers the work performed by Owens-Corning Fiberglas Corporation at Granville, Ohio under Contract No. PH-22-68-64 during the period April, 1968 to February, 1970.

The contract was under the technical direction of James F. Durham, NAPCA, Cincinnati, Ohio.

The program was conducted by the New Glass Development Department of the Owens-Corning Fiberglas Technical Center. Mr. F. Munro Veazie was program technical manager, Mr. William H. Kielmeyer was principal investigator and Mr. T. F. McGann was administrative manager.

Many of the pieces of equipment mentioned in this report were commercial items that were not developed to operate as applied during this study. Any failure to meet the objectives of this study is no reflection on any of the commercial items discussed herein or on any manufacturers.

PART 1

PROGRAM DIGEST

I. INTRODUCTION

Fabric filters have, for many years, been used by various industries for removing fine solid matter from exhaust or flue gas streams. Recently, the metals industries have found that when reactive materials are injected into the flue gas streams, such filters can also be used to reduce certain objectionable gaseous components in these streams. The materials act to combine physically or chemically with such gases, converting them to solid form. The fabric, in turn, provides a surface upon which the products of the reaction can be collected and also functions to keep the unreacted material in the path of the gas flow. In the aluminum industry, injecting activated alumina dust into a fabric filter house resulted in a substantial decrease in the concentration of gaseous hydrogen fluoride emanating from the electrolytic reduction of aluminum oxide.

For its role in objectionable gas removal, the fabric filter seems particularly well suited, for several reasons. It permits, for example, the use of extremely fine reactant particles to enhance both the rate and extent of gas absorption. Because fabric filtration is dry, it provides the products of reaction in a form that normally requires little or no treatment before either disposal or subsequent use. Also, the fabric filter affords at least two ways that the reactant can be introduced to the waste stream - either by direct injection into the stream ahead of the fabric or by exposure after being deposited on the fabric surfaces -- and each of these methods can

lead to kinetically different gas-solid responses. Specifically, if the method of introduction is by direct injection, the reactant behaves like a fluidized (transport) bed from the point of injection to the point of collection on the filter surfaces and thereupon it acts like a fixed bed. When deposited on the fabric surfaces initially, the reactant functions exclusively like a fixed bed.

The principal limitation of fabric filters in general is temperature, most commercially available filters are unable to survive for long periods much above 550°F. This limits the use of many of the more promising gas reactants which function most efficiently at temperatures well above the filter capability. Slaked lime, a strong SO_2 absorbent, for example, has its highest removal capacity at around 800°F.

Recognizing that a need existed for a filter fabric able to withstand high temperatures, Owens-Corning Fiberglas Corporation (OCF) carried out an extensive in-house program to develop such a material. The result was an S-glass cloth treated with a proprietary inorganic finish which preliminary investigations indicated would resist degradation by temperature to 1200°F. In order to evaluate the new fabric as a filtering media, OCF subsequently built at corporate expense a stainless steel fabric filter test facility capable of simulating many field applications to temperatures

up to 1000°F. The test facility can be used to assess both the filtration characteristics of a fabric and the chemical contacting characteristics of fabric filters.

Under contract with the Division of Process Control Engineering of the National Air Pollution Control Administration, Owens-Corning embarked on a program to evaluate the chemical contacting potential of fabric filters with emphasis on the 600-1000°F temperature range according the new fabric capability. The gas selected for investigation was SO_2, a toxic air pollutant, currently being discharged into the atmosphere by industrial sources at a rate of 32 million tons annually. In this investigation, the SO_2 was carried in flue gases that closely resembled in composition the effluent of coal-burning facilities, since these units constitute the major SO_2 emission sources. The reactants chosen for consideration consisted of materials which had demonstrated ability to remove SO_2 in other investigations.

II. TEST EQUIPMENT AND OPERATING PROCEDURE

OCF had made several equipment changes* in their small scale filter bag test facility to meet the conditions required for obtaining meanful data on SO_2 removal.

A schematic representation of this test facility is presented in Figure 1. Arrows indicate the direction of flue gas flow during test operation.

Currently the facility is equipped to provide:

1. A preselected effluent gas composition from a natural gas source (see Table 2 of Part II).
2. Controlled effluent gas temperatures in the range from 300°F to 1000°F.
3. Injection of special gases such as SO_2 at various concentrations.
4. Reactant injections at various stoichiometric ratios**.
5. SO_2 monitoring on both the input side and the output side of the bag house.
6. Reactant and particulate matter collection in a six bag (each 5 3/4" diameter x 68" long) stainless steel bag house.
7. Measurement and control of gas flow rate between 200 and 600 cfm.

A detailed description of the equipment is included in Part II of this report.

---

* All changes were corporately funded.

** Stoichiometric ratio, as applied to this report, represents the ratio of the weight of reactant injected to the weight which would theoretically be required to combine with all of the special gas in the stream. A stoichiometric ratio of 2.0 indicates that twice as much material is added as is required by chemical balancing.

SCHEMATIC DRAWING OF PROCESS

FILTER BAG PILOT TEST FACILITY

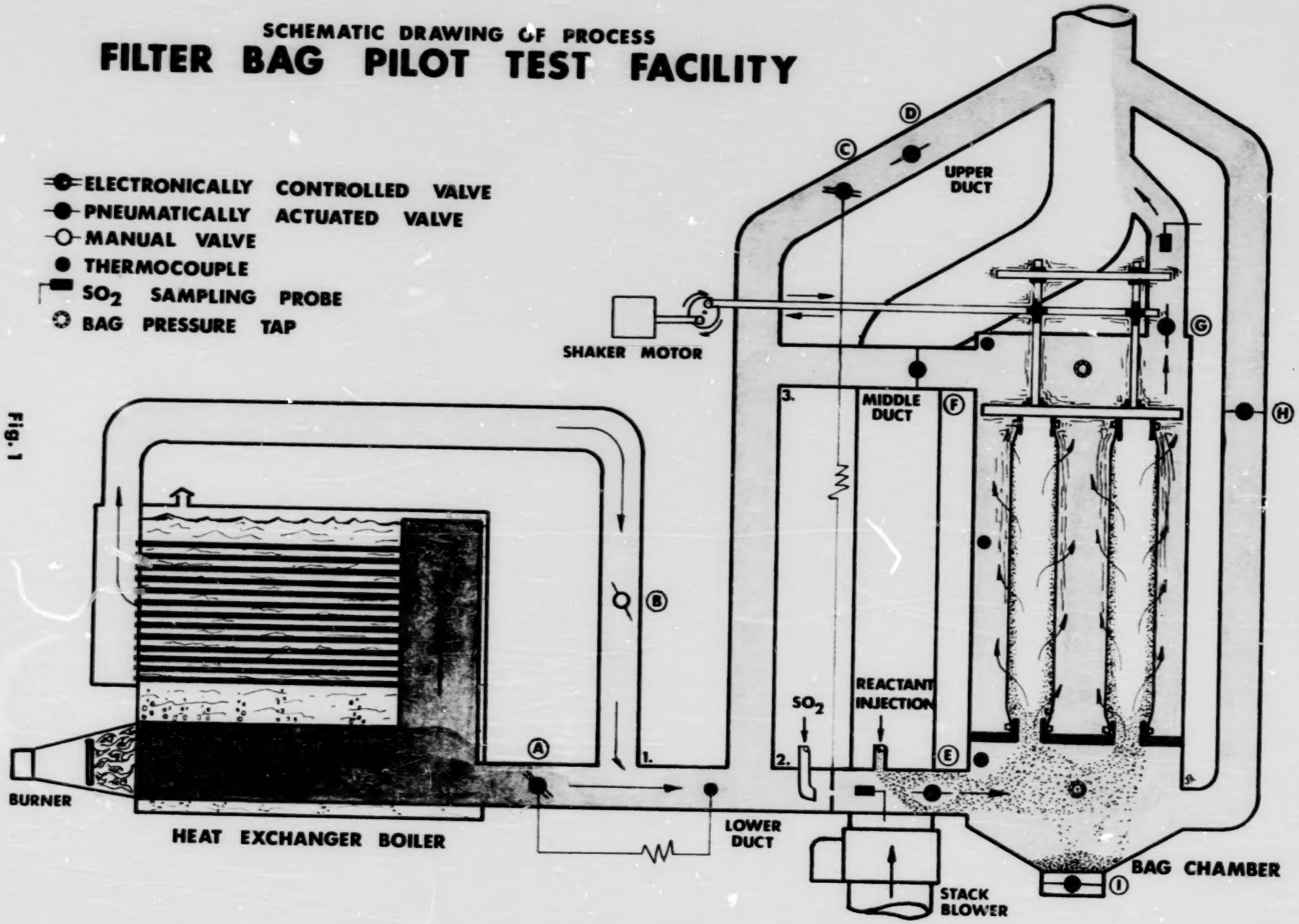


Fig. 1

The testing program involved the evaluation of seven fine-grained materials as SO_2 sorbents under various conditions of gas stream temperature, flue gas flow rate, and reactant input level. The reactants examined were slaked lime, slaked dolomitic lime, promoted slaked lime (slaked lime containing 1% NaCl which was dissolved in the slaking water), promoted slaked dolomitic lime (also containing 1% NaCl), manganese dioxide, alkalized alumina, and Nahcolite (a mineral composed of approximately 70% sodium bicarbonate). Each of these was tested in a narrow range of temperatures which, according to previous investigations, resulted in peak capacities for SO_2.

Two methods were used to introduce the reactant to the SO_2: (1) continuous injection into the flue stream before the bag chamber, and (2) deposition on the bag surfaces in advance of the stream. In one investigation, fly ash was admitted along with reactant to ascertain whether or not the fabric filter could be used to remove both solid and gaseous pollutants simultaneously. In all cases, the SO_2 content of the input gas was held to approximately 2800 ppm.

In each experiment, the test equipment was first brought to equilibrium at the selected test temperature. The flue gas flow rate was set at the required value, and depending on whether the reactant and SO_2 were

brought together by continuous injection or by bag precoating, the SO_2 or reactant was admitted to the gas stream. In continuous injection, the SO_2 injection rate was adjusted to bring the effluent to the established SO_2 content and after stream conditions had stabilized, the reactant was introduced at the selected stoichiometric level. In bag precoating, SO_2 was admitted after the stream had transported all of the required amount of reactant to the surfaces of the bags. With either mode of reactant-gas contact, measurements were made of the SO_2 content of the input and output gases, the pressure drop across the bags, and the temperature of the bag house during SO_2-reactant interaction.

Bag cleaning was accomplished by reverse air flow and shaking of the bags. Between the test and cleaning periods, samples of solids which had fallen to the base of the bag chamber were taken for sulfur determination. A new set of bags was installed for each new reactant or every 72 operating hours whichever occurred first.

III. RESULTS AND DISCUSSION

Typical SO_2 breakthrough patterns obtained during experimentation are shown in Figures 2 and 3. The sharp drop followed by a more gradual decline in SO_2 concentration pictured in Figure 2 is common among tests involving continuous injection of reactant. The S-shaped curve of Figure 3, on the other hand, accrues to tests in which the bags were precoated; this latter curve is representative of breakthrough patterns obtained with many fixed bed reactors.

If, in Figure 2 or 3, the area between the breakthrough curve and the line representing the initial SO_2 concentration in the flue gases is divided by the time of the test, the average concentration of SO_2 removed during the run is obtained. Joining together the average removal values from several related tests yields a set of curves like that of Figure 4, which shows the association between percent SO_2 removal, bag temperature, and reactant input level for one absorbent. Curves such as these have been used to compile Table I, which summarizes the findings of all tests involving continuous reactant injection.

A. Slaked Limes and Slaked Dolomitic Limes

As Table I indicates, the slaked limes and slaked dolomitic limes look particularly attractive for removing SO_2 from gas streams at high temperatures. Of the two types of reactant, though, the slaked lime demonstrated a slightly higher removal capacity under the same operating conditions. Maximum absorption with both types of material occurred at 800°F.

TYPICAL SO_2 BREAKTHROUGH PATTERN
CONTINUOUS REACTANT INJECTION

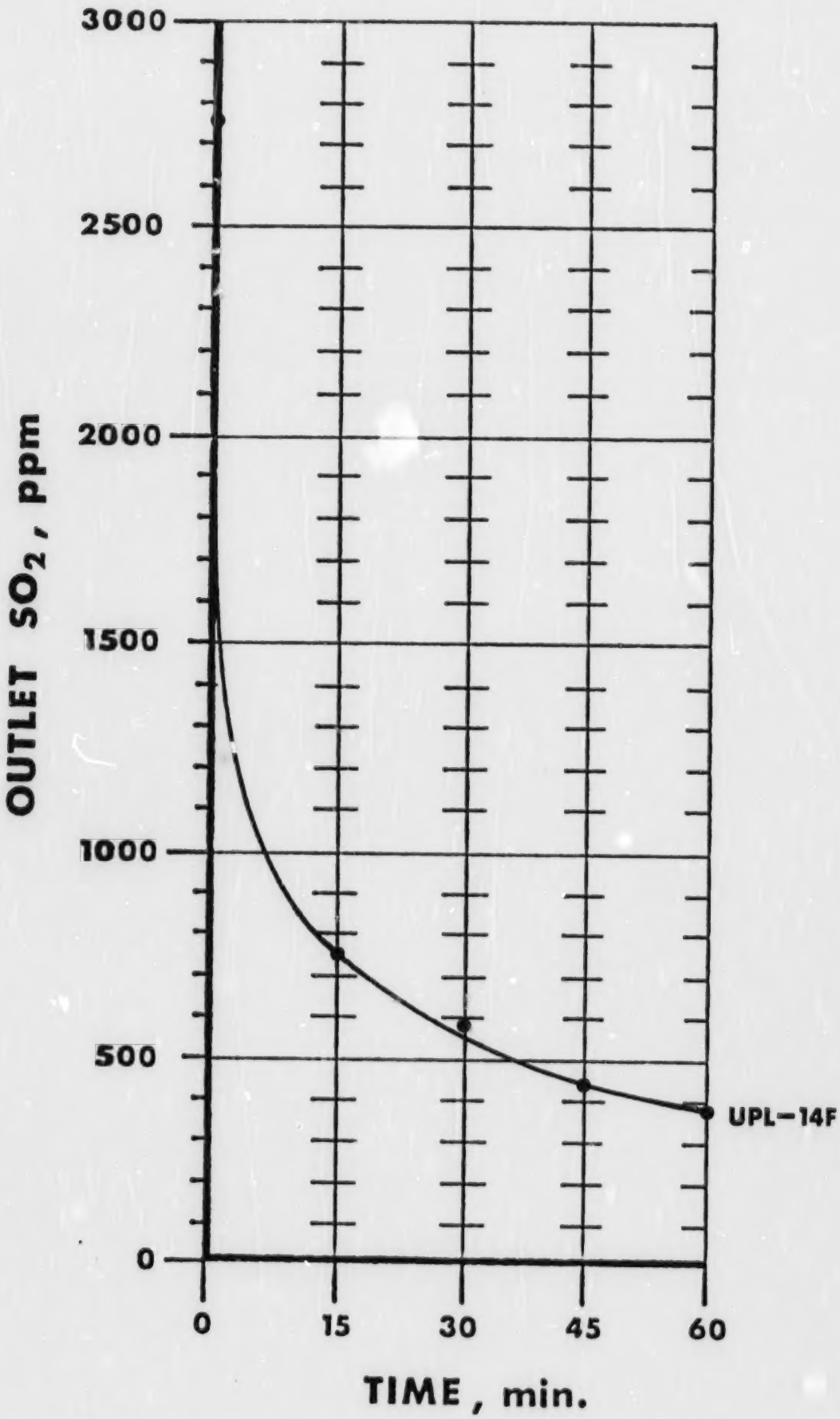


Fig. 2

TYPICAL SO_2 BREAKTHROUGH PATTERN
PRECOATED BAGS

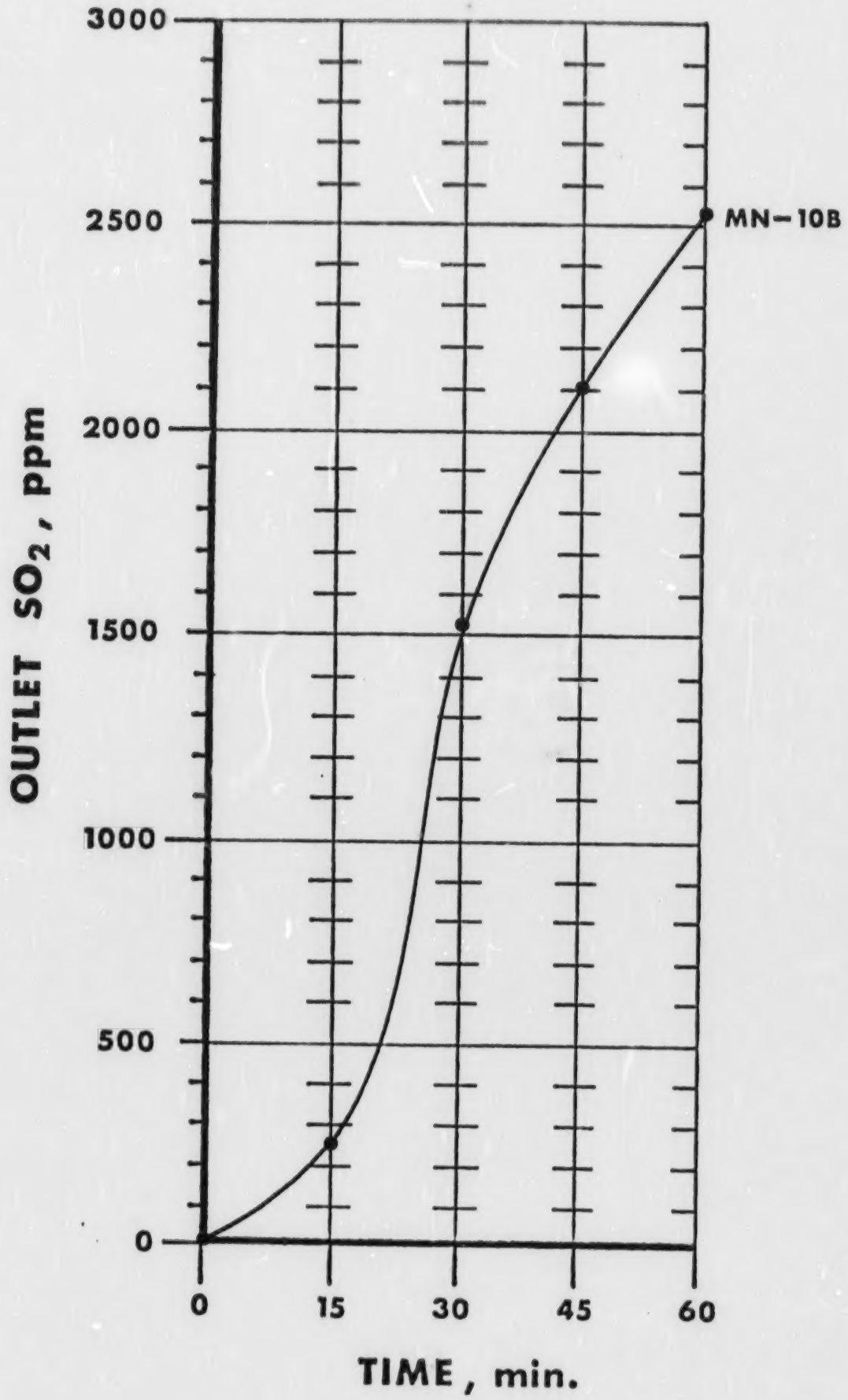
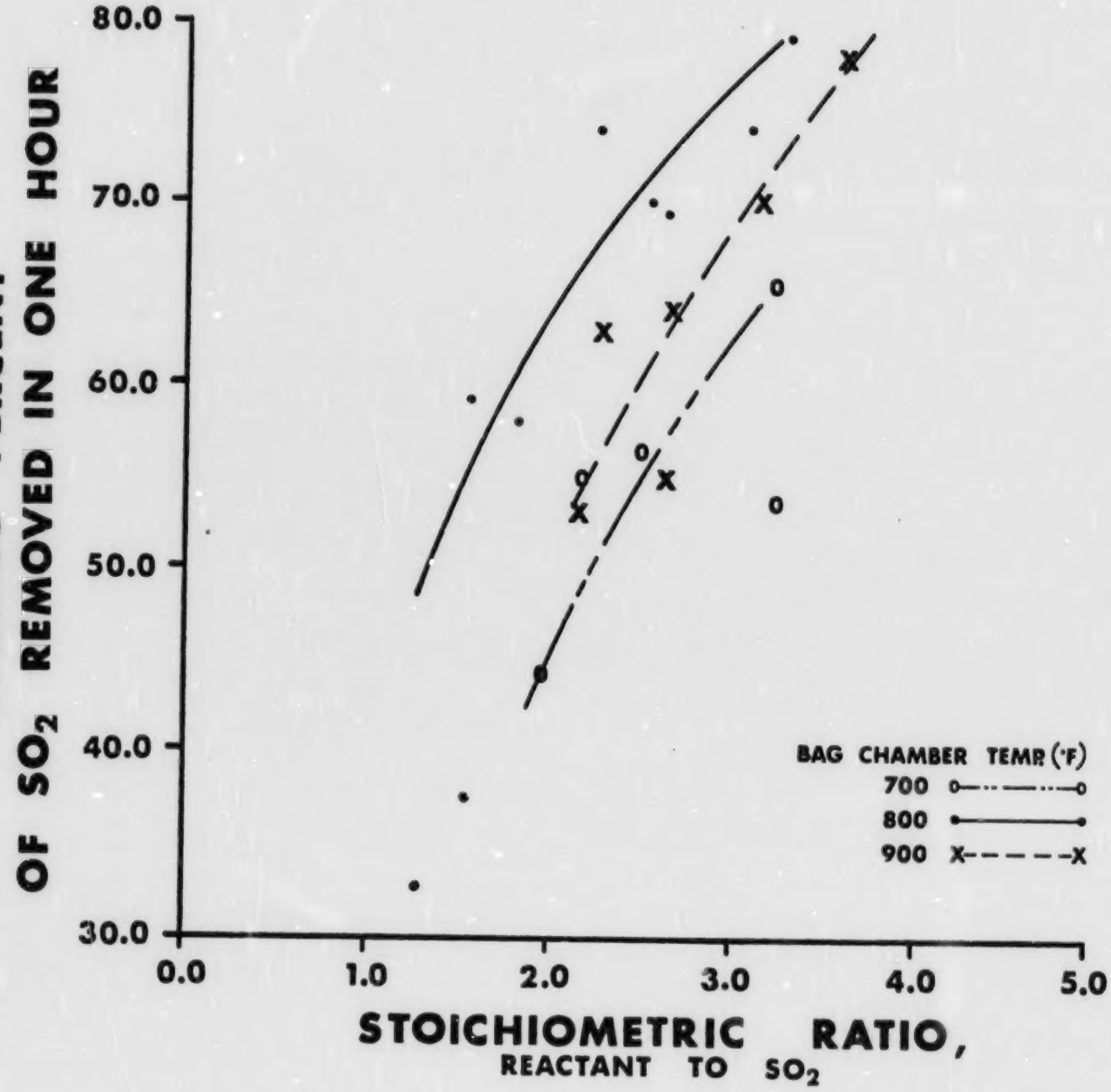


Fig. 3



REMOVAL OF SULFUR DIOXIDE WITH SLAKED LIME AT AIR/CLOTH RATIO OF 6.0 ft./min.

Fig. 4

Table 1

Sulfur Dioxide Removal with
Continuous Reactant Injection

Reactant: Slaked Lime

Flow Rate:	290 cfm			385 cfm	
Stoichiometric Level:	1.0	2.0	3.0	2.0	3.0
Bag Temperature					
700°F	--	46%	64%	57%	74%
800°F	40%	65%	78%	81%	91%
900°F	--	52%	70%	65%	81%

Reactant: Promoted Slaked Lime (1% NaCl)

Flow Rate:	290 cfm		
Stoichiometric Level:	1.0	2.0	3.0
Bag Temperature			
700°F	--	55%	68%
800°F	41%	66%	80%
900°F	--	56%	70%

Reactant: Slaked Dolomitic Lime

Flow Rate:	290 cfm			385 cfm	
Stoichiometric Level:	1.0	2.0	3.0	2.0	3.0
Bag Temperature					
700°F	--	40%	54%	40%	52%
800°F	30%	52%	64%	55%	70%
900°F	--	34%	49%	44%	60%

Reactant: Promoted Slaked Dolomitic Lime (1% NaCl)

Flow Rate:	290 cfm			385 cfm	
Stoichiometric Level:	1.0	2.0	3.0	2.0	3.0
Bag Temperature					
700°F	--	43%	55%	44%	60%
800°F	28%	51%	69%	55%	73%
900°F	--	50%	65%	60%	69%

Reactant: Manganese Dioxide

Flow Rate:	290 cfm			385 cfm	
Stoichiometric Level:	1.0	2.0	3.0	2.0	3.0
Bag Temperature					
500°F	--	62%	72%	56%	70%
600°F	28%	54%	74%	57%	74%
700°F	--	58%	73%	60%	73%

Reactant: Alkalized Alumina

Flow Rate:	290 cfm	385 cfm
Stoichiometric Level:	1.0	1.0
Bag Temperature		
300°F	--	97%
400°F	80%	93%
500°F	60%	74%

Reactant: Nahcolite

Flow Rate:	290 cfm	385 cfm
Stoichiometric Level:	0.8	0.7
Bag Temperature		
300°F	59%	60%

Increasing the gas stream flow rate sharply increased the SO_2 conversion. Also, promoting the lime reactants tended in general to enhance absorption, but the effect was relatively minor except for

slaked dolomitic lime at 900°F. Increased removal at higher flow rates indicates that diffusion or mass transfer is controlling the gas-solids reaction.

Despite the high SO_2 removal values obtainable with the slaked limes and slaked dolomitic limes, the relatively high stoichiometric input rates necessary to achieve these results show that the reactant utilization (the proportion of reactant involved in the conversion) and hence the reaction efficiency were very low. In fact, as can be determined by dividing the removal values in Table I by the appropriate stoichiometric terms and then comparing the results, increasing the reactant input to absorb more SO_2 netted a decrease in reactant utilization. Slaked lime, for example, at one stoichiometric input level, captured 40% of the SO_2 from an 800°F gas stream flowing at 290 cfm; however, when discharged into the same stream at three times stoichiometric requirements, it removed less than twice as much SO_2 -- its efficiency (removal per stoichiometric input value) had dropped from 40 to 26%. Obviously, consideration of the slaked limes and slaked dolomitic limes as reactants in a commercial SO_2-removing venture must take into account the added cost per unit quantity of SO_2 removed which would accompany a rise in SO_2 conversion. The low efficiency of SO_2 removal by slaked lime and

slaked dolomite may require, for economic reasons, the regeneration of the products of reaction in specific emission cases.

B. Manganese Dioxide

Manganese dioxide is unique among the candidate reactants tried. Within experimental conditions, its ability to remove SO_2 did not appear to be affected by either flue gas flow rate or temperature. Moreover, increasing the stoichiometric input level of MnO_2 increased SO_2 conversion but not at a major expense to reactant utilization.

Because of its high cost, the utility of manganese dioxide as a reactant in commercial applications depends strongly on its ability to be regenerated. Beinstock and Field* found several ways of converting the product of reaction, $MnSO_4$, to a reactive form of manganese oxide; chemical oxidation with either $(NH_4)_2S_2O_8$ or Na_2CO_3 and electrolysis looked especially promising from a technical standpoint.

However, before MnO_2 can be considered for large-scale SO_2-removing applications, the efficiencies and expense of these regeneration processes would have to be evaluated.

---

* Beinstock, D. and Field, F.S. "Bench-scale Investigation on Removing Sulfur Dioxide from Flue Gases," J. Air Pollution Control Ass'n., v. 10 n. 2, April 1960, pp 121-125.

C. Alkalized Alumina

Clearly, alkalized alumina ranks as a very promising absorbent. As Table I shows, it functioned well at low temperatures, its removal efficiency was high, and like the slaked limes and slaked dolomitic limes, it became more respondent to SO_2 at higher flue gas flow rates. At a temperature of 300°F and a flow rate of 385 cfm, one stoichiometric level of alkalized alumina absorbed nearly 100% of the SO_2 present in the gas stream.

The high removal value obtainable with alkalized alumina in a filter baghouse is meaningful, for fabric filters can accept reactant particles down to 0.5 micron in diameter. The use of finely divided reactant largely eliminates the problem of mechanical attrition of particles, a factor which has plagued many removal processes requiring large alkalized alumina grains.

The regeneration of fine particle size reacted alkalyzed alumina has not been investigated on a large scale. The economics of such regeneration would have to be determined before the overall economics of the use of alkalyzed alumina can be established.

D. Nahcolite

Although a subject of limited experimentation, Nahcolite responded favorably with sulfur dioxide in all cases. Like alkalized alumina, it operated at low temperatures and was efficient, absorbing 75 and 85% of its potential capacity at 290 cfm and 610 cfm respectively.

It is not known if Nahcolite can be regenerated. Also, accurate data on the cost of the material are not currently available. The use of Nahcolite in many emission source streams would probably be too expensive unless regeneration were possible or some application could be made for the reaction products. Sodium sulfate, the principal product of conversion, is extremely water soluble; if deposited or otherwise left to itself without further processing, it could develop into a serious water pollution problem.

E. Precoating versus Continuous Addition

All of the results reported above pertain to reactants which were introduced directly into the sulfur-bearing stream. As mentioned earlier (Page 1), there are two regions in the filter bag chamber where chemical combination can occur: one is the "so-called" transport section in front of the bags where the reactant particles are entrained in the gas stream, and the other is on the surfaces of the bags where the particles are finally deposited. It is of interest to know what

portion of the SO_2 conversion is traceable to which section, and in particular, what proportion can be relegated to the fixed bed on the bag surfaces. One possibility for doing this lies in a comparison of the sulfur contents of solids which had collected in the base of the bag chamber before and after the bags were cleaned. Presumably, the solids which had settled out before cleaning (the "fallout") were those which had initially been captured by the gas stream but lacked sufficient momentum to reach the surfaces of the bags. A sulfur analysis of this material would reflect reaction in the transport region only*. The material recovered after cleaning (the 'dust cake") on the other hand consisted of particles which had traveled the entire length of the reaction zone in the bag unit and then became attached to the bags. Its sulfur content would reflect reaction in both regions. The portion of SO_2 conversion taking place specifically on the bags could be determined by noting the difference in the analyses of the two samples.

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* Presuming the fallout to be representative of entrained material may be an oversimplification. All fallout deposits contained some solids which had been part of the dust cake, but became dislodged from the bags at the end of the run due to a sudden easing of bag flexure. Moreover, the assumption was made that once the solids had settled out of the stream they were no longer capable of absorbing SO_2. Observations indicate that the sulfur contribution made to the fallout by the dust cake and the stream after particle settling was slight.

The sulfur concentrations of reaction products from several representative tests are contained in Appendix D. Because these values are presented as weight percents, only approximate indications of the extent of reaction in each region can be given. According to this listing, the site of the reaction depended on the reactant involved. With promoted slaked dolomitic lime, 40 to 60% of the conversion occurred on the bags. With alkalized alumina, manganese dioxide, the slaked limes and unpromoted slaked dolomitic lime, more than 70% of the appropriate reaction took place during transport. These percentage figures are only approximate. Further experimentation would be required to establish the exact values.

When precoating was used to introduce reactant into the filtering system, bag coating was achieved by entraining the reactants in a hot SO_2-free flue gas stream directed through the bag house. When the desired stoichiometric ratio of material had built up on the bags, SO_2 was admitted to the stream above the baghouse and the concentration of the gas beyond the bag house was monitored. All of the calcium-based reactants -- the slaked limes and slaked dolomitic limes -- responded poorly to the SO_2, because they had reacted with CO_2 in the flue gas stream prior to SO_2 introduction.

Manganese dioxide, not being affected by CO_2 in the coating stream, was capable of removing large amounts of SO_2. At a stoichiometric ratio of 3.0 and a gas flow of 385 cfm, it consumed nearly 90% of the SO_2 at temperatures between 500 and 700° F.

F. Fly Ash Addition

With reactant and fly ash both entrained in the flue gas stream, no loss of reactant activity with SO_2 was observed. In fact, two of the five reactants tested - promoted dolomitic lime and MnO_2 - actually removed more SO_2 with fly ash present than when it was absent.

Based on these findings, a filter bag unit could serve both as a chemical contactor for gas removal and as a collector of particulate matter simultaneously. Elimination of solid pollutants upstream from a baghouse would depend on factors other than gas removal efficiency, factors such as the end use of the solids collected in the baghouse and the expense of processing them for this use.

IV. CONCLUSIONS

The results of this study have demonstrated the technical feasibility of using a glass fabric filter bag house as a collector of reacted materials and as a contactor for reactants to remove objectionable gases from exhaust gas streams up to temperatures of 900°F.

Of the reactant materials investigated in the temperature range of 700°F to 900°F, slaked lime and slaked dolomite are possible candidates for SO_2 removal in the filter bag system from a standpoint of reactant efficiency, total SO_2 removal and potential economical cost.

In the temperature range of 300°F to 500°F, alkalyzed alumina proved to be very effective for SO_2 removal, but would probably require regeneration for its economical use.

Nahcolite, a naturally occurring sodium bicarbonate, is also effective in removing SO_2 in the temperature range of 300°F to 500°F but would also require regeneration to be economical.

Manganese dioxide can be used most effectively in the temperature range of 500°F to 700°F, but also requires regeneration to be economically useful.

V. RECOMMENDATIONS

The results and conclusions reached under this contract lead to several questions, the answers to which would lead to better understanding of the mechanism of SO_2 removal and permit an economic analysis of the system to be made.

In the filter bag house test facility at OCF, the distance from reactant injection to the entrance of the effluent gas into the bags is only two feet. If this distance were increased, it might result in increased SO_2 removal because of increased exposure time of reactant to SO_2 gas. Lower stoichiometric ratios could show better reactant utilization under the longer exposure time and thus reduce reactant costs in field applications. This factor should be investigated.

Referring to the observation of increased SO_2 removal at higher effluent gas flow rates, no attempt was made to determine the effect of reactant particle size and shape on SO_2 removal at different gas and flow rates. It is possible that reactant particle size and shape will be a factor under such conditions. If acceleration of the reactant particle is part of the phenomenon of increased SO_2 removal at higher flow rates, it seems logical that reactant particle physical characteristics are unimportant. The effect of reactant particle size and shape on SO_2 removal at various

effluent gas flow rates should be established. This can be an important factor in the economics of SO_2 removal.

In these studies, the SO_2 content of the input effluent gas was maintained at 2800 ppm in all experiments. The effect of higher and lower SO_2 effluent gas contents on the removal rate of the various reactants should be studied. It is quite possible that there may be fairly large differences in the reaction rates of the various reactants at varying SO_2 effluent gas contents. The costs for SO_2 removal could be majorly effected by this factor.

The mechanism for SO_2 reaction under dynamic conditions should be studied in more detail. It can have major effects on the choice of reactant and its physical characteristics, and on the amount of reactant used. Economics for field applications of the bag house system can be more firmly set when the reaction mechanism is established.

The high temperature filter bag developed by OCF has not had large scale field trials. This can be an important economic factor in the use of the lower cost reactants such as slaked limes and dolomites. Bag life should be established to allow economics for field applications to be projected.

No work in this investigation was carried out on techniques of regeneration of the reactants after use. There are some reports in the literature of

the possibility of transforming $CaSO_4$ and $MnSO_4$ to the basic oxides. The regeneration of the reactants can have an important impact on the economics of field operation and on waste disposal problems. This should be established.

PART II

PROGRAM DETAILS

I. EQUIPMENT DESCRIPTION

There are four basic elements which compose the equipment used in the project: (1) a boiler assembly which produces flue gases that are channelled to the remainder of the test facility; (2) a system for injecting SO_2 into the flue gas stream; (3) a reactive dust feeder which discharges into the stream; (4) a filter bag chamber which serves to collect the solid material in the stream and also to support any reaction between the injected dust and SO_2. In addition to these elements, there are various regulatory and control mechanisms to maintain stream temperature, stream flow rate, and the concentration of SO_2 in the flue gases. Also provided are sensors for measuring and recording pertinent test information such as SO_2 content upstream and downstream of the bag chamber, and bag pressure loss. All of these components are shown in functional perspective in Figure 1 (which was presented in Part I of this report). An actual picture of the test facility appears in Figure 5.

The function of the boiler assembly, shown on the left of Figure 1, is to provide simulated flue gases representative of the products of coal-burning but without SO_2. To form these gases, natural gas and air are combined in a special nozzle-mixing burner system, rated at 1,980,000 Btu/hr. A gas/air ratio regulator located in the natural gas line ahead of the burner permits adjustments in the air inlet supply to vary the quantity of flue gases generated without varying their compositions.

FILTER BAG TEST FACILITY

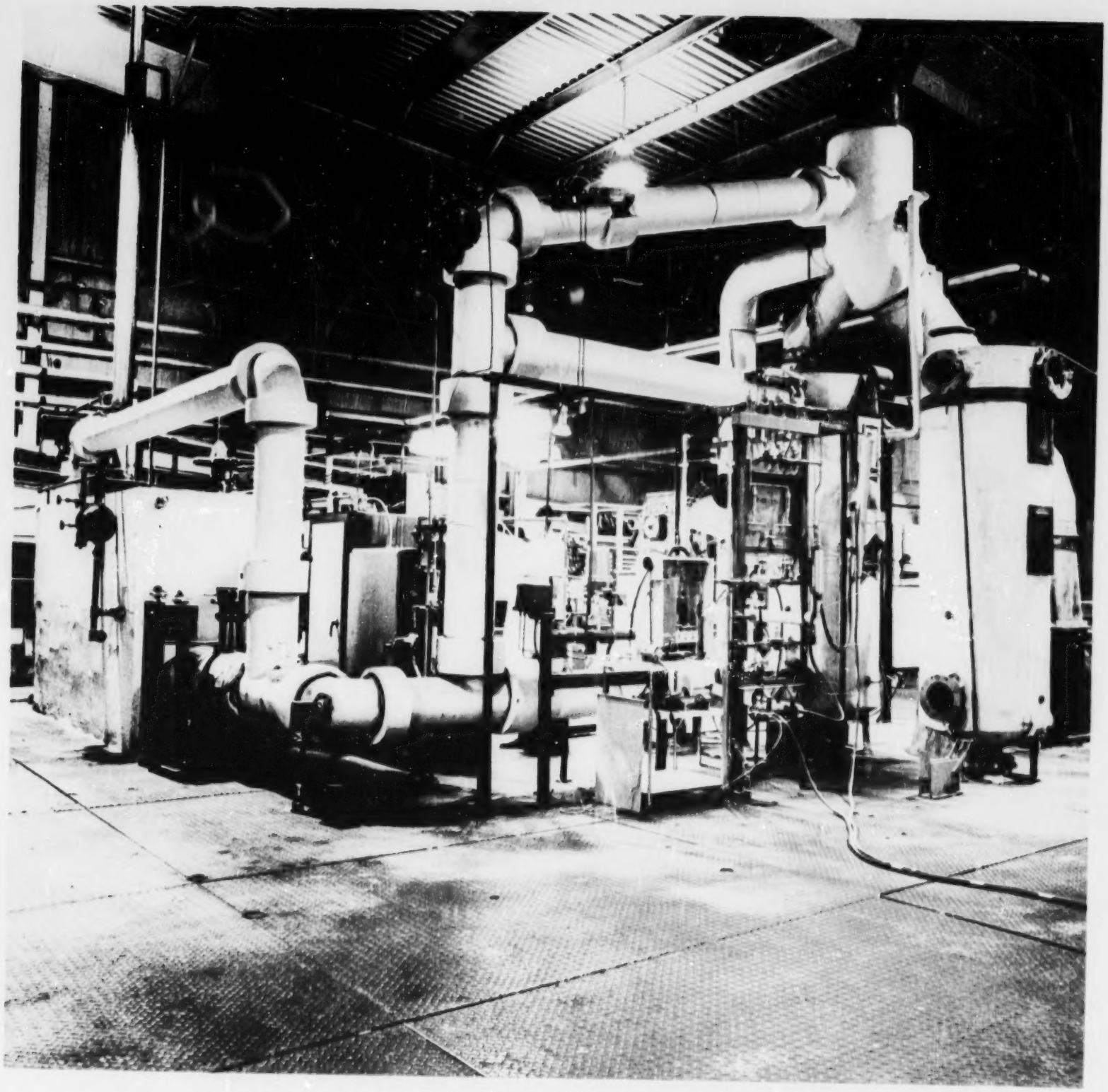

Fig. 5

The boiler proper* consists basically of a long combustion tube which connects to the burner, a vertical transport shaft, and a parallel arrangement of 116 small cooling tubes; all of these are sealed and immersed in water, as shown in the schematic in Part I of this report. Exhaust gases from the burner pass along the combustion tube and then divide into two branch streams; one of these streams passes directly through to the outside of the boiler at a temperature of approximately 1400°F; the other branch stream passes back into the upper part of the boiler box through the small cooling tubes where its temperature is lowered to about 250°F. The proportion of gases flowing through each branch is regulated by a butterfly valve in the stream outside the boiler proper. Valve B**,which is in the 250°F line, is manually operable; Valve A in the 1400°F branch is governed by a thermocouple located downstream from Tee 1 where the two branch streams rejoin. By automatic manipulation of Valve A and manual adjustment of Valve B, confluent stream temperatures (temperatures downstream of Tee 1) ranging from 250°F to 1000°F are possible without the need for changing natural gas and air valve positions in the lines leading to the burner. Because of the heat exchanger-boiler and a gas/air ratio

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* designed for Owens-Corning Fiberglas by Babcock and Wilcox Company, Barberton, Ohio.

** refer to Figure 1 for the locations of valves and other designated items

regulator employed in the unit, the boiler assembly as a whole is capable of supplying flue gases at variable flow rates and temperatures without significantly affecting their composition. Flue gas analyses made on samples taken from the confluent stream attest to this capability (see Table 2).

After leaving the boiler assembly, flue gases may traverse any of three paths in the course of a test run. The routes taken depend on the stage of the test--experimental, cleaning, or intermediate. During the experimental stage, sometimes referred to in this report as the filtering cycle, some of the gases pass through the lower duct and enter into the base of the filter bag chamber. The rest of these combustion products, however, bypass the bag chamber and go directly to the stack. Control Valve C in the upper duct, activated by an orifice plate in the lower duct, determines the proportions of gases following each route. The main purpose of this control system is to compensate for variations in flow resistance in the bag house by forcing more or less of the flue gases through the lower duct as the pressure rises or falls respectively. In this way the flow rate of gases into the bag house is maintained constant. Valve D, located in the upper duct, remains open during the entire filtering cycle.

As gases flow through the lower duct, they pick up SO_2 and SO_2 reactants. The SO_2 used is commercial grade (99.9% pure) bottled gas

Table 2

Flue Gas Analysis*

Flue Gas Temperature (at thermo-couple controlling Valve A)	Inlet Air Setting (fraction of full open)	Percent of Volume				
		H_2O	N_2	O_2	Ar	CO_2
700°F	3/4	3.8%	82.1%	5.1%	1.0%	8.0%
300°F	1/2	2.8	83.1	4.7	1.0	8.5
700°F	1/2	3.8	80.1	7.3	.9	7.9
800°F	3/8	3.2	80.6	4.8	1.1	10.4
1100°F	1/2	3.2	79.5	6.1	.9	10.3

* by mass spectrometer

material. It is introduced into the flue gas stream ahead of the orifice plate under 20 psig pressure. The rate of flow is regulated using a standard rotameter with a stainless steel float and 1/4 inch diameter tube. A commercially available vibrating screw feeder provides reactant injection at a controlled rate. An air jet at the end of the feeder tube aids in dispersing the reactive powder in the flue stream.

The filter bag chamber (Figure 6) is essentially a large stainless steel cylinder with a shallow conical base. The unit can accomodate eight bags 68 inches long by 5-3/4 inches I. D.; in this program only six bags were used at a time. As shown in Figures 1 and 6, the bags are fitted over collars on two stainless steel baffle plates. The lower mounting plate is fixed, i. e. welded completely to the side of the chamber, and has openings at the center of the collars. The top plate, on the other hand, is completely solid but is smaller than the bottom plate and is suspended by two rods from an external bracket. During the filtering cycle, gases flowing into the bottom of the chamber rise through the openings in the lower mounting plate into the center of the bags, pass through the bag walls where they deposit entrained dust, and exit the chamber around the periphery of the top mounting plate. The gases enter the stack above the bag chamber by means of the duct containing Valve G.

FILTER BAG CHAMBER

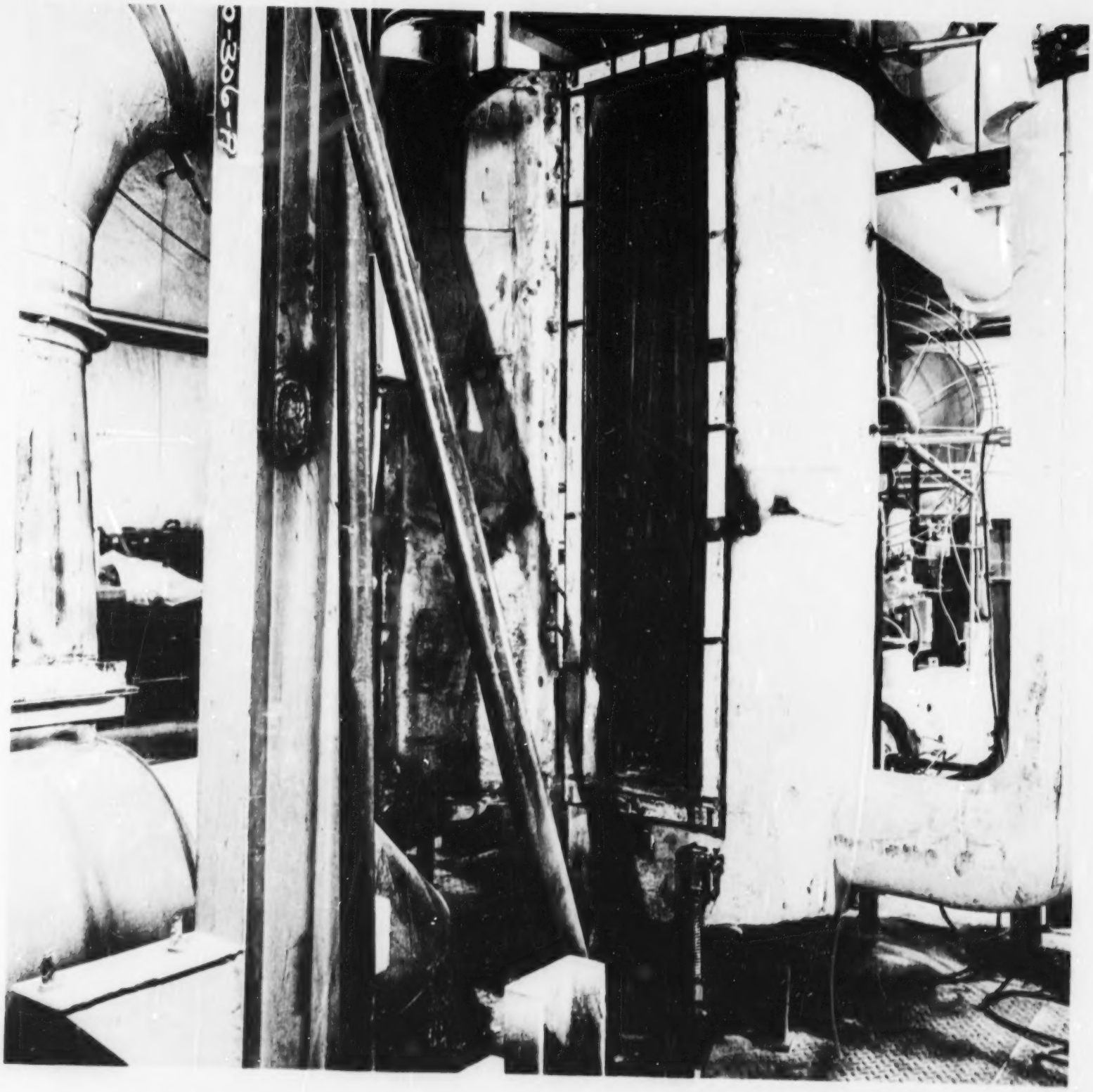

Fig. 6

In and around the bag chamber, there are three sets of sensors provided to monitor the condition of the gas stream as it passes through the bags. Thermocouples in the top, middle, and bottom sections of the chamber sense gas temperatures. Two ports, one below and one above the bags, are provided for measuring pressure loss across the bags resulting from the accumulation of reactive dust on their surfaces. Additionally, two gas sampling probes are inserted in the unit, one upstream from the bag house in the lower duct and one downstream in the duct containing Valve G. Each sampling line is equipped with particulate matter and water vapor removal apparatus as indicated in Figure 7. Both of the lines feed into a modified infrared detector which preferentially monitors SO_2 concentration in the gas stream.

The description of the test facility thus far has centered around the flow of flue gases during the experimental stage of testing. There are, as mentioned earlier, two other stages of the test operation -- a cleaning stage and an intermediate stage. In neither of these stages do the gases pass through the lower duct into the base of the filter bag chamber. In the cleaning stage, designed to free the bags of dust accumulated during filtering, some of the gases enter the top section of the bag chamber through the middle duct, flow backwards through the bags, and exit to the stack through the duct containing Valve H. As during the filter cycle, a portion

SCHEMATIC DRAWING OF PROCESS

SO_2 SAMPLING SYSTEM

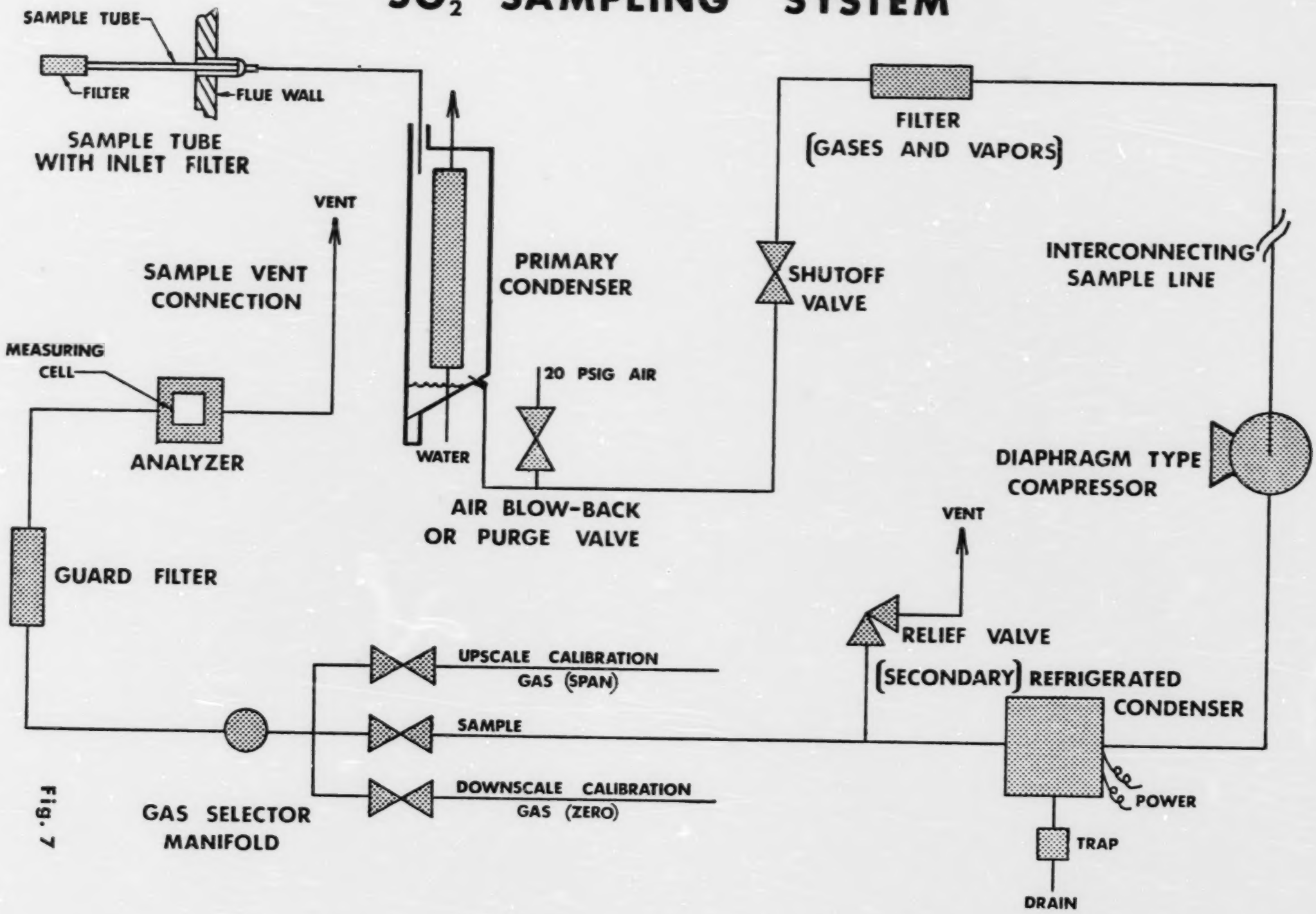

Fig. 7

of the gases goes directly to the stack through the upper duct. Valve D (rather than Valve C which is fully open during cleaning) controls the proportion of gases entering the bag chamber. It is fitted with mechanical stops; the degree to which Valve D is opened depends on how encrusted the dust layer is on the bag surfaces.

In addition to reverse air flow, cleaning is also effected through mechanical shaking of the bags. A motor-driven eccentric, connected to tie rods above the top bag-mounting plate, vibrates the tops of the bags at about 200 cycles a minute over a 1-1/2 inch horizontal span.

Immediately before and after the cleaning stage, all of the combustion gases pass through the upper duct. These periods constitute the intermediate stages of testing. During these times, Valve I can be manually opened to allow filtered dust to be deposited in a drum for sampling and weighing.

II. TEST PROCEDURE

A. General

The test procedure was generally the same from one run to the next.*

Before each run, hot flue gases from the boiler were introduced into the base of the filter bag chamber to bring the chamber to the required test temperature (as determined by the center thermocouple). When this temperature was reached and could be maintained at the gas flow rate specified for the test, SO_2 was injected into the flue gas stream. The rotameter on the SO_2 input line was adjusted until, according to the SO_2 analyzer, the concentration of the toxic gas downstream from the bags had stabilized around 2800 ppm. At this point, additive dust was injected into the stream at a controlled rate, and the test started.

During the run, which was timed and normally lasted one hour, the following information was recorded continuously:

(a) the temperatures at the top, middle, and bottom of the bag chamber,

(b) the pressure drop across the bags,

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* with the exception of the Precoated Bag Study

(c) the concentration of SO_2 on the "clean" side of the bags.

At the end of the run, the SO_2 and additive feed system shut off automatically, Valves G and E closed, and all of the flue gases bypassed the bag chamber completely. Valve I was opened to remove material which had settled to the bottom of the bag chamber during the run. This fallout was weighed, and samples were taken for sulfur analysis.

After removal of fallout matter, the bags were cleaned. The dust-cake which was dislodged from the bags was collected for sampling and weighing.

Examination of test equipment prior to the start of the project study had revealed that the variable speed reactant feeder was unable, at constant dial settings, to reproduce delivery rates within acceptable limits. This failing negated the planned method for determining the weight of material expended during a test, which was based for each reactant on a fixed relationship between reactant delivery rate and feeder dial setting. As an alternative approach, a volumetric procedure was devised. This consisted of first establishing a reference level of material in a narrow section of the hopper, adding a known amount of reactant above this level before a run, and after the run, adding or removing material until the reference level was again

established. The weight of material initially added, plus or minus the weight of reactant added or removed at the end of the run respectively was considered the weight of reactant consumed by the test. In preliminary investigations, this volumetric approach netted results that were within 2% of the actual weights delivered. Since the margin of error is within the limits of accuracy for the entire filter bag system, this method was adopted for use in the test program.

So that comparisons could be made between the abilities of several additives to remove SO_2 under similar conditions, the amount of material injected into the stream was converted from a weight to a stoichiometric basis*. The formula for this conversion is:

$$S = \frac{Wr\ (T + 460)}{5.95 \times 10^{-4}\ cft\ M}$$

Where S = the stoichiometric ratio of additive to SO_2

Wr = the weight in grams of solid sorbent used during the run

T = the temperature of reaction in °F -- equivalent to the middle bag chamber temperature

c = the concentration level of SO_2, in ppm, before reactant contact

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* one stoichiometric input level of additive is the amount (or weight) of dust theoretically capable of reacting with all of the SO_2 in the gas stream.

t = the time of the run, in minutes

M = the gram equivalent weight of the solid additive, i. e. the weight of material in grams necessary to completely react with 64. 0 grams of SO_2 on a theoretical (non-kinetic) basis

Derivation of this formula appears in Appendix A.

All of the tests conducted as part of the program were incorporated into four study series -- the Additive Study, Flue Gas Flow Rate Study, Precoated Bag Study, and Fly Ash Study. The following sections describe the major objectives sought and test conditions for each of these study series.

B. Additive Study

In the first study series, major emphasis was placed on evaluating seven promising materials as SO_2 sorbents under various conditions of bag chamber temperature and additive level. The seven candidates were slaked lime, promoted slaked lime (1% NaCl), slaked dolomitic lime, promoted slaked dolomitic lime (1% NaCl), manganese dioxide, Nahcolite (a naturally occurring mineral consisting of 70% $NaHCO_2$), and alkalized alumina. Of these materials, Nahcolite and alkalized alumina were in short supply and were added to the flue gas stream only near 1. 0 stoichiometric level. All other additives were discharged into the stream at from 1. 0 to 3. 0 times stoichiometric

input requirements. Each type of additive dust was studied in a temperature range which earlier reports indicated facilitated peak SO_2 removal. For Nahcolite and alkalized alumina, this temperature range was 300°F to 500°F; for MnO_2 , it was 500°F to 700°F; and for the calcium based additives, the range was 700°F to 900°F.

All other factors which could affect the sorption rates were held constant. Except in the alkalized alumina tests, which ran for 30 minutes, the normal test operating or filtering time was 60 minutes. In all of the tests the SO_2 concentration in the flue gases did not vary more than 100 ppm from 2800, cleaning time was maintained at 10 minutes, and the flow rate was 290 cfm, which corresponds to an air-to-cloth ratio of 6.0 ft/min.

C. Flue Gas Flow Rate Study

The second study series involved determination of the impact of the flue gas flow rate on SO_2 removal. The space velocity of the stream was raised from its former value of 290 cfm to 385 cfm, a value corresponding to 8.0 ft/min air-to-cloth ratio. Many of the tests conducted under the additive study were rerun here, although with the faster gas stream.

D. Fly Ash Study

The third study series treated the effect of fly ash on SO_2 removal. The ash, an incombustible solid by-product of coal-burning, is present in flue gas streams emanating from coal-fired boilers. Fly ash does not itself react with SO_2; however, in some removal processes it interferes with the treatment of SO_2 and therefore must be withdrawn from the flue gas stream ahead of the SO_2 reaction chamber. The third study series was executed to determine if fly ash can be tolerated in the filter bag process, or if some means has to be provided to eliminate it before the SO_2 can be treated.

In carrying out this investigation, it was necessary to blend the fly ash with the solid reactant and feed both from the additive feeder, for no provision in the test facility was made to inject fly ash singly. Five reactants were considered -- two limes, two dolomitic limes and manganese dioxide -- and each was mixed with the fly ash so that under presumed test conditions, two stoichiometric levels of reactive dust would be injected and the concentration of fly ash would be four grains/cu. ft. of flue gas. Two runs were made per mix (except in the case of MnO_2), the second being essentially a repeat of the first. All of the limes and dolomitic limes were tested

at 800°F bag temperature; the MnO_2 runs were made with the bag temperatures at 600°F. The stream flowed constantly at 385 cfm.

E. Precoated Bag Study

The fourth study series considered a second method of introducing the reactive additive material to the SO_2. In the first three study series, unreacted dust was injected directly into the SO_2-laden stream and deposited (along with reacted material) on the filter bags. In the second method, additive material was deposited on the bags before the sulfur-containing gases were admitted into the filter bag chamber. The study was conducted principally to examine the performance characteristics of a reactant as a thin fixed bed on the surfaces of the bags.

The procedure used in this test series differed only slightly from that used previously. To coat the bags, a precalculated quantity of reactant was discharged into the flue gas stream, which was free of SO_2, and transported to the bag surfaces. The stream flow rate and temperature were approximately equal to those required for the actual run. Before the test started, reactant which had settled to the bottom of the bag chamber during coating was removed and weighed, and the difference between this weight and the weight of material discharged into the stream was considered to be the amount

of dust on the bags available for absorption. When SO_2 was released into the gas stream at a predetermined rate of flow, the run began. The same bag temperature, gas flow rate, bag pressure drop and SO_2 concentration measurements taken during trials in the first three study series were also recorded in these trials. Dust cake and fallout were likewise sampled for sulfur content.

The choices of parameters to be investigated were nearly the same as in the continuous-coating trials. The low-temperature materials, alkalized alumina and Nahcolite, were unavailable; manganese dioxide, promoted and unpromoted slaked lime and dolomitic lime, the high temperature reactants, were involved in these tests in the same ranges of stoichiometrics as in the Additive and Flow Rate Studies. Gas flow rates were 290 and 385 cfm as before; as in the earlier study, temperatures of the bags were selected to complement the particular reactant under consideration. The only basic difference between these studies and the series of studies which preceded them was the manner in which the reactive material was brought into contact with the SO_2-bearing stream.

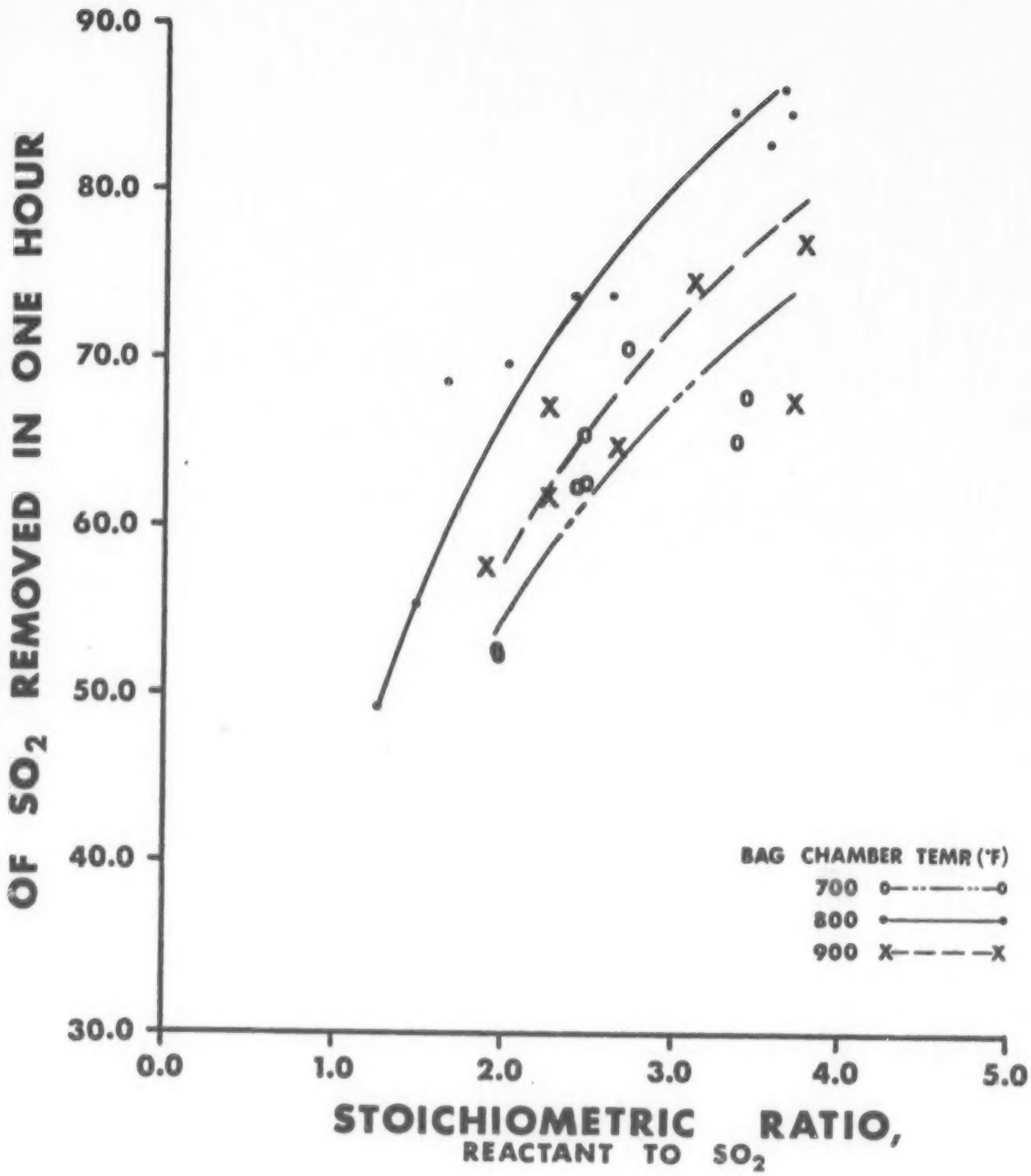
III. RESULTS

Sulfur dioxide breakthrough curves and bag pressure loss curves taken from representative tests are pictured in Appendix B. Appendix C contains in tabular form pertinent data from all the tests performed. The results of sulfur analysis on several selected dustcake and fallout sample pairs are found in Appendix C. In both Appendices D and C the test findings are grouped according to the study under which the tests were performed.

A. Effect of Reactant Type on SO_2 Removal

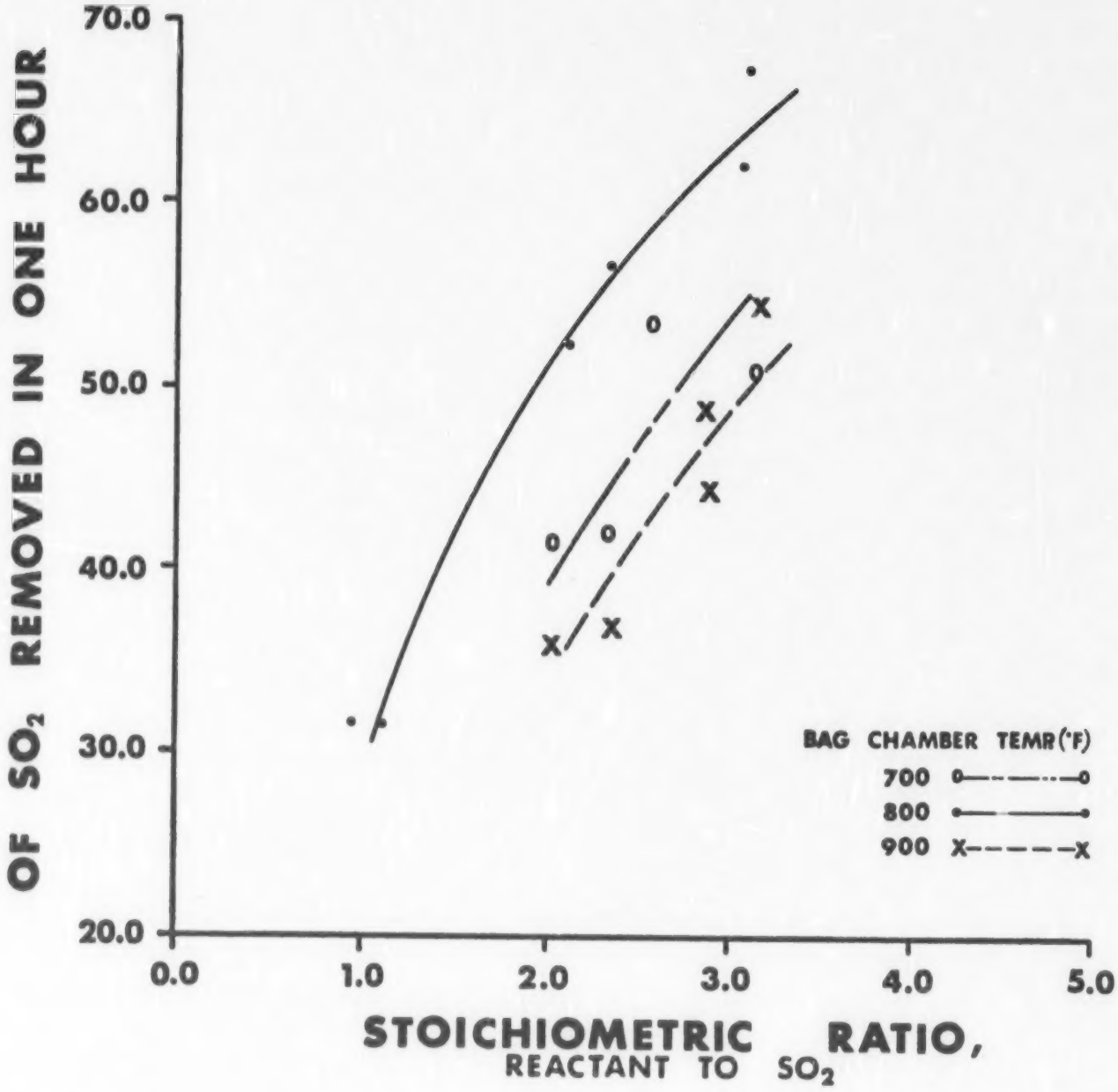
If the findings of the various tests from the Additive Study are analyzed and compared, several general observations can be made. Some trends are particularly evident in the curves in Figure 4 and in Figures 8 to 11, which summarize the SO_2 removal data obtained from the lime and manganese dioxide trials.

The slaked lime and slaked dolomitic limes look very attractive as SO_2 sorbents at 800°F. Of the two, however, the slaked limes demonstrated a much greater capacity for SO_2. This finding is supported in Table 3, which lists the reactants and the highest SO_2 removal values obtained with them at each of three stoichiometric levels.



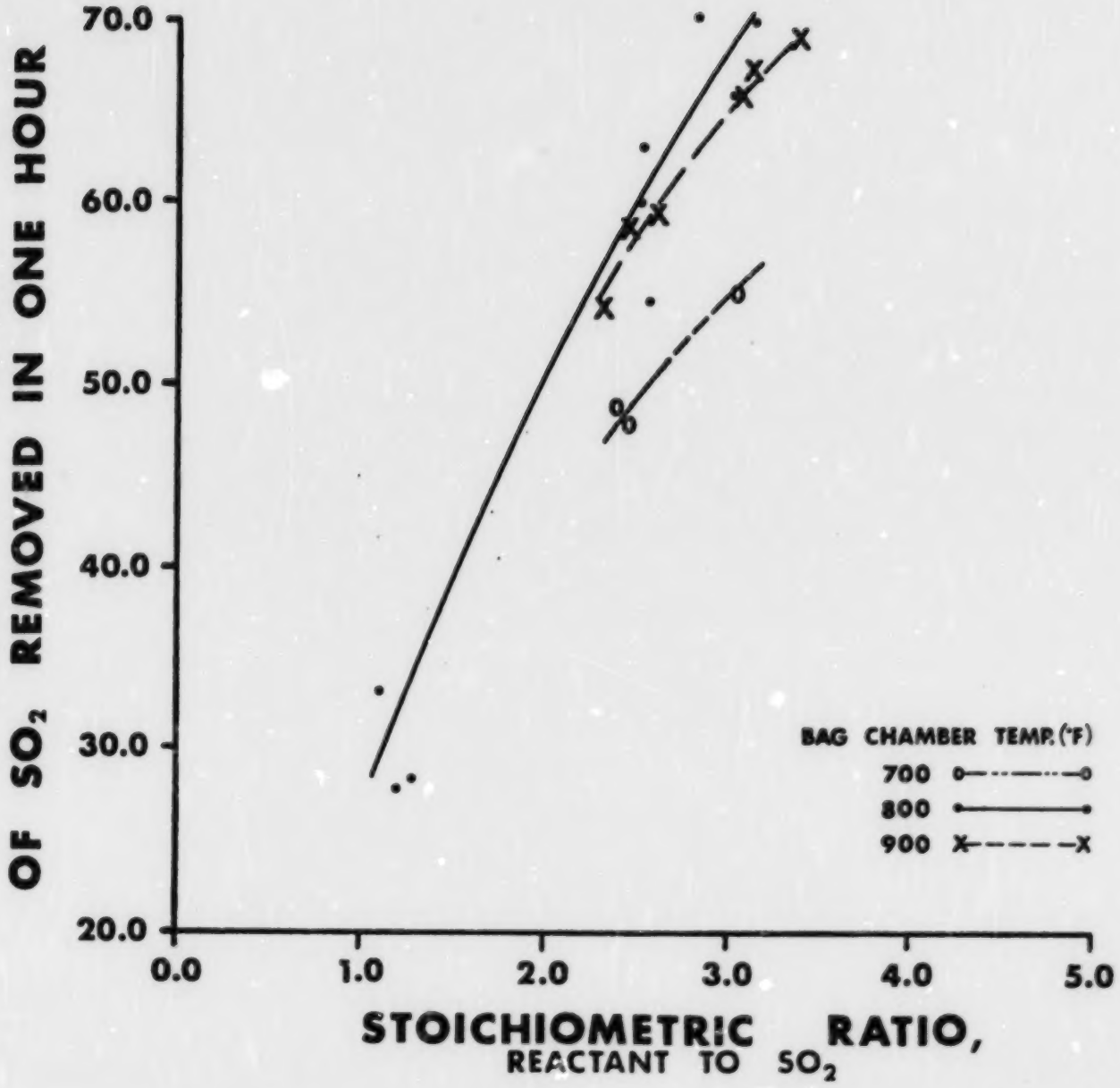
REMOVAL OF SULFUR DIOXIDE WITH SLAKED LIME (1% NaCl) AT AIR/CLOTH RATIO OF 6.0 ft./min.

Fig. 8



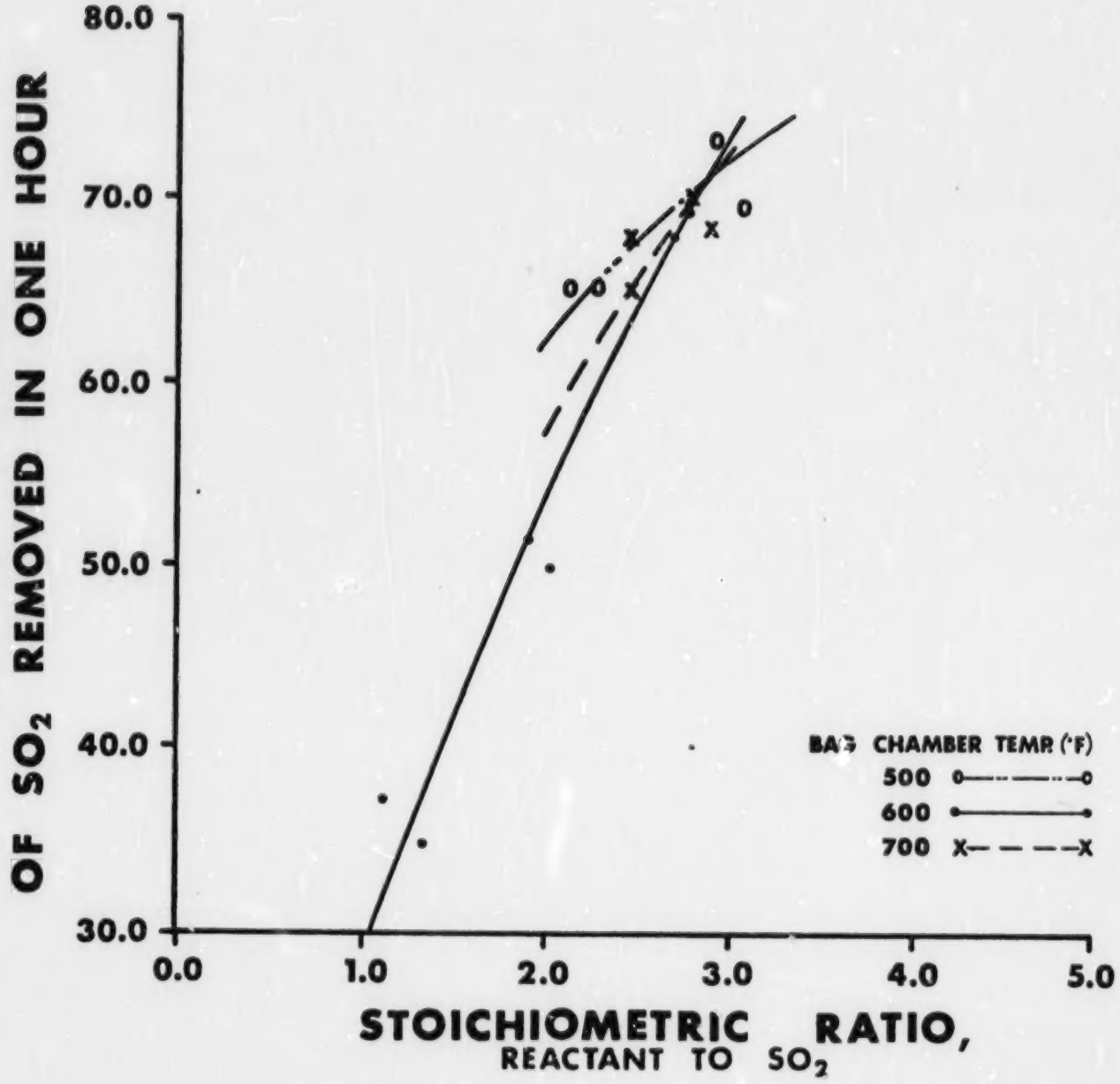
REMOVAL OF SULFUR DIOXIDE WITH SLAKED DOLOMITIC LIME AT AIR/CLOTH RATIO OF 6.0 ft./min.

Fig. 9



REMOVAL OF SULFUR DIOXIDE WITH SLAKED DOLOMITIC LIME (1% NaCl) AT AIR/CLOTH RATIO OF 6.0 ft./min.

Fig. 10



REMOVAL OF SULFUR DIOXIDE WITH MANGANESE DIOXIDE AT AIR/CLOTH RATIO OF 6.0 ft./min.

Fig. 11

Table 3

Maximum Average Mole Percent SO_2 Removed

Reactant	Stoichiometric Levels 0.75	1.0	2.0	3.0
1. Promoted Slaked Lime	--	41%	66%	80%
2. Unpromoted Slaked Lime	--	40	65	78
3. Manganese Dioxide	--	28	62	74
4. Promoted Slaked Dolomitic Lime	--	28	51	69
5. Unpromoted Slaked Dolomitic Lime	--	30	52	64
6. Alkalized Alumina	65%	--	--	--
7. Nahcolite	59	--	--	--

The slaked limes achieved between 40 and 80% removal of SO_2 at 800°F and at stoichiometric levels of from 1.0 to 3.0; the dolomitic limes removed between 30 and 70% under the same conditions.

Promoting slaked lime with 1% NaCl generally enhances its SO_2 removal ability. The effect is almost negligible when the bag temperature is 800°F, particularly at low stoichiometries, and also at high additive levels when the bag temperature is 900°F. However, at 700°F bag temperatures, there is an increase of about nine percent points at 2.0 stoichiometry (from 46 to 55%) and four percentage

points at 3.0 stoichiometry (64 to 68%). There is a four percentage point increase at the 2.0 stoichiometric level (52 to 56%) when the bag temperature is 900°F.

Promoting slaked dolomitic lime with NaCl increases its capacity for SO_2 at high stoichiometric levels and high temperatures. The effect is particularly apparent at 900°F; unpromoted dolomitic lime absorbed only 34% of the SO_2 at a stoichiometry of 2.0 and only 49% at 3.0; promoted dolomitic lime, on the other hand, removed 50% at 2.0 and 65% at 3.0, a 16 percentage point increase at both additive levels. Virtually no difference in performance of the promoted and unpromoted slaked dolomitic limes is observed at 700°F and at low stoichiometrics at 800°F.

Manganese dioxide falls slightly below the slaked limes in ability to remove SO_2, according to Table 3. However, it functions at lower gas stream temperatures. Figure 11 also shows that temperature has little effect on the percent of SO_2 that manganese dioxide removes.

The low temperature reactants, Nahcolite and alkalized alumina, both have large capacities for SO_2. Nahcolite, when introduced into the gas stream at 300°F (mid-bag temperature) and 0.77 stoichiometric level, removed 59% of the gas -- a 77% reaction efficiency.

Alkalized alumina did somewhat better at the same temperature, removing 64% of the SO_2 with only 0.78 stoichiometric requirements of material. The scarcity of Nahcolite prevented its use in more than one trial in the Additive Study.

The fact that alkalized alumina demonstrated a high absorption efficiency (82%) is meaningful. This material has drawn considerable attention as an SO_2 reactant, not only because of its affinity for the gas but also because it is regenerable and yields desirable sulfur as a by-product of the regeneration process.

In the past, studies of alkalized alumina reactions have been restricted to vertical absorption towers where the reactant was either suspended in a rising column of flue gases or entrained in the gas stream and collected in a plenum chamber for recycle. In order that a reasonably fast current of gases could be maintained without solids carryover, it was necessary that the size of the reactant particles be large, on the order of 1/16 inch in diameter. Moreover, to be economical to use, alkalized alumina had to be able to undergo several regeneration cycles without loss of absorption capacity. The reactant met the latter condition, but successive regenerations of the pellets eventually weakened them to the point that they were vulnerable to attrition damage and could no longer be used in the towers. Largely

because of this factor, alkalized alumina in pellet form is no longer considered a sufficient absorbing candidate in fluidized beds. In filter bag systems, by contrast, the mechanical stability of reactant particles presents no problem since filter bags can contain solid matter finer than one micron in size. In fact, fabric filtration requires the use of much finer (spray-dried) alkalized alumina than would be acceptable in most fluidized bed systems. Whether or not the finer particles are kinetically more active with SO_2 than the pellets and can be satisfactorily regenerated was not studied in this program, but should be considered in future investigations.

The curves in Figure 4 and in Figures 8 to 10 indicate that although there is an increase in the amount of SO_2 absorbed with increasing level of reactant added, the efficiency of the reaction or the reactant utilization drops off. The meaning of this trend in terms of the economics of SO_2 removal is clear; the higher the quantity of SO_2 removed with a given material under a fixed set of operational conditions, the higher the unit cost (cost per quantity of SO_2 removed) of the process, of regeneration and of solid waste disposal. Reactant utilizations at various stoichiometric levels are presented in Table 4.

Table 4

Maximum Average Mole Percent SO_2 Removed per Molar Equivalent of Reactant

Reactant	Stoichiometric Levels 0.75	1.0	2.0	3.0
1. Promoted Slaked Lime (1% NaCl)	--	41%	33%	27%
2. Slaked Lime	--	40	33	26
3. Manganese Dioxide	--	28	31	25
4. Promoted Slaked Dolomitic Limes (1% NaCl)	--	28	26	23
5. Slaked Dolomitic Lime	--	30	26	21
6. Alkalized Alumina	80%	--	--	--
7. Nahcolite	77	--	--	--

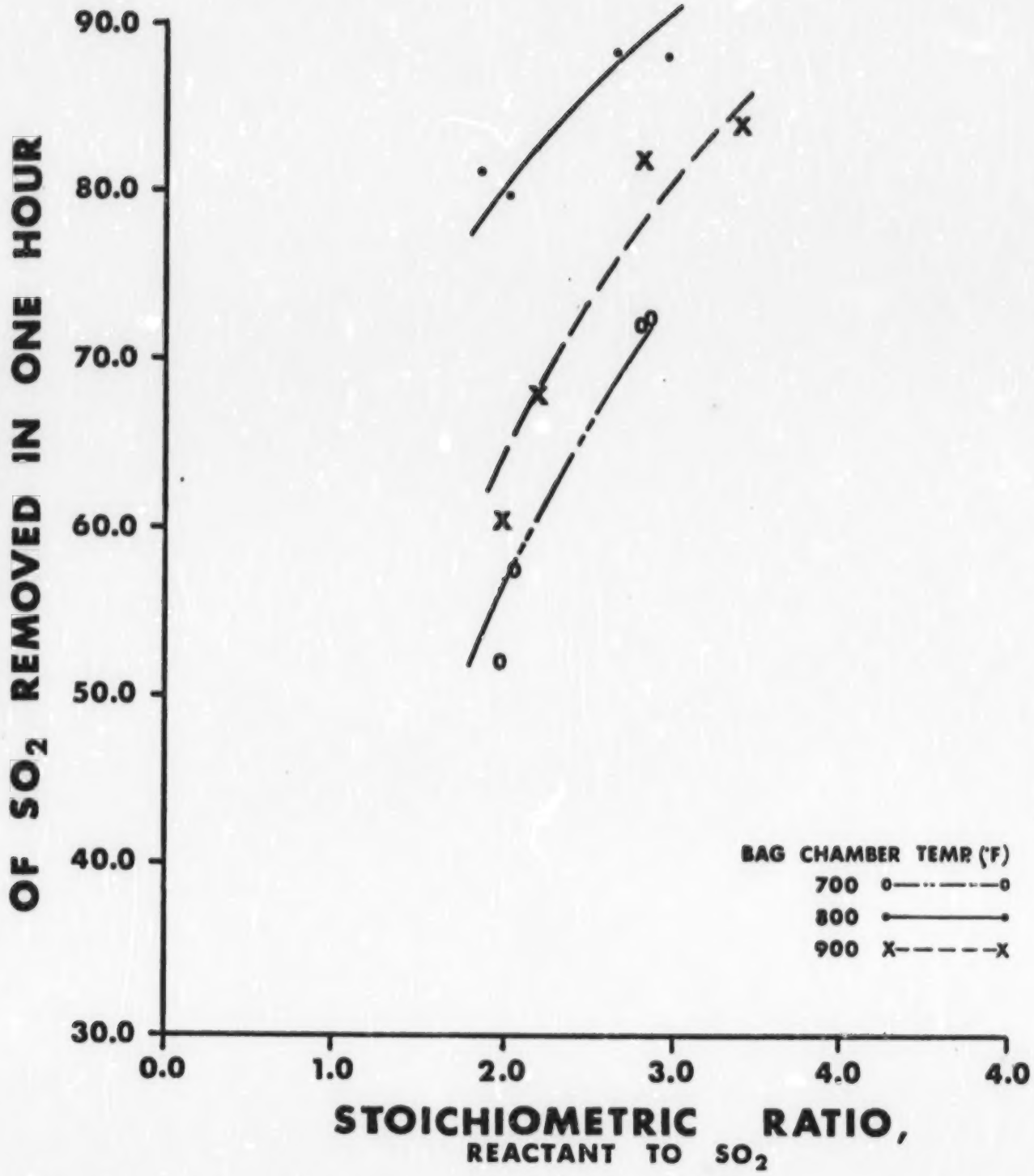
In summarizing the results of the additive study series, we note that the inexpensive, readily available reactants, notably the limes, require higher temperatures for absorption and are less efficient than alkalized alumina and Nahcolite which are both costly and hard to procure. The addition of NaCl to the limes generally aids absorption. Manganese dioxide, although not especially a strong reactant, is less influenced by temperature than any of the other materials tested.

B. Effect of Flue Gas Flow Rate on SO_2 Removal by Various Additives

The results of the flow rate test series are summarized in Figures 12 through 15 for the various limes and MnO_2, and in Figure 16 for alkalized alumina. Only two tests were run with Nahcolite, one at a gas flow rate of 685 cfm (14.0 fpm air-cloth ratio) and mid-bag temperature of 500°F, the other at a gas flow rate of 610 cfm (12.0 fpm air/cloth ratios) and a temperature of 300°F. These results (along with those of the other materials) are listed in Appendix C.

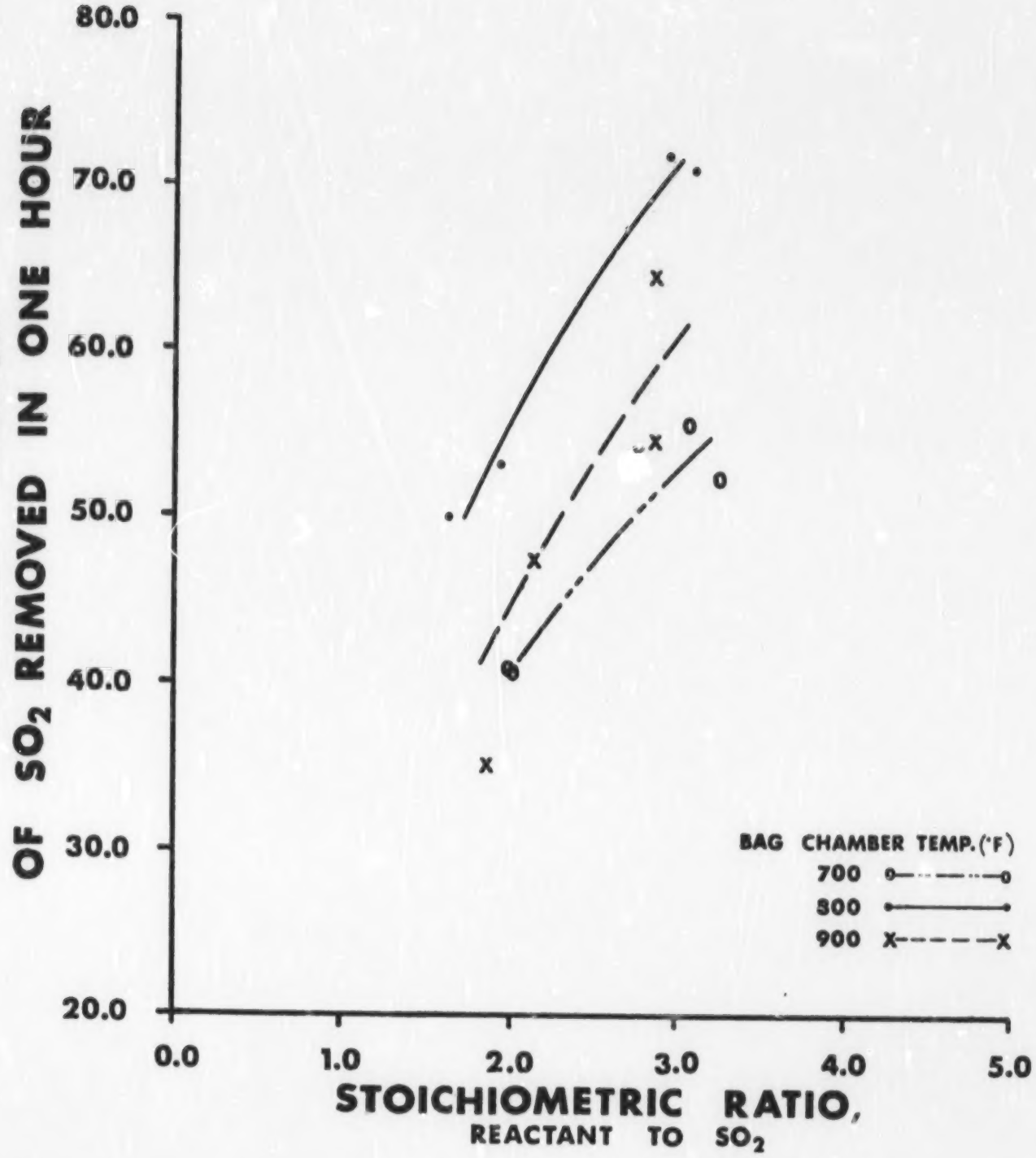
Some of the numbers from the above sources are incorporated in Table 5 which also contains (for comparison purposes) some results from the additive study. Excluded from the list of reactants is promoted slaked lime; it could not be fed consistently enough at the high flow rate to produce reliable data.

From the table it is apparent that with most of the reactants, the increase in flue gas flow rate has resulted in an increase in the proportion of SO_2 absorbed. In terms of the kinetics of reaction between gases and solids, this finding is significant for it indicates that diffusion or mass transfer controls the rate of SO_2 conversion. The fact that the residence time, or the time available for absorption, is reduced at the higher gas flow rate is perhaps offset by increased turbulence in the stream which would increase particles - SO_2 confrontation, by greater SO_2 striking force, and by more dust being injected into the stream.



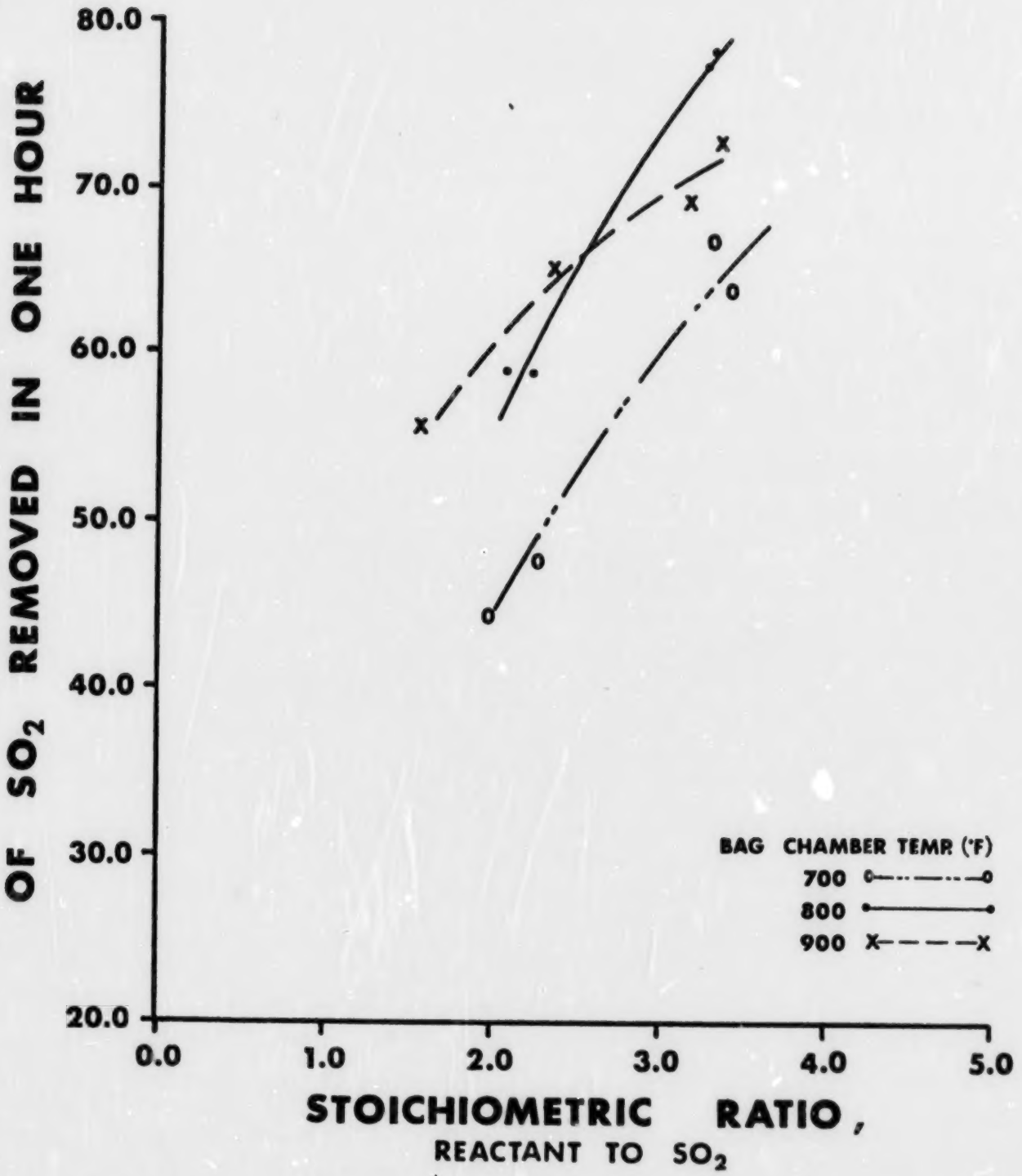
REMOVAL OF SULFUR DIOXIDE WITH SLAKED LIME AT AIR/CLOTH RATIO OF 8.0 ft./min.

Fig. 12



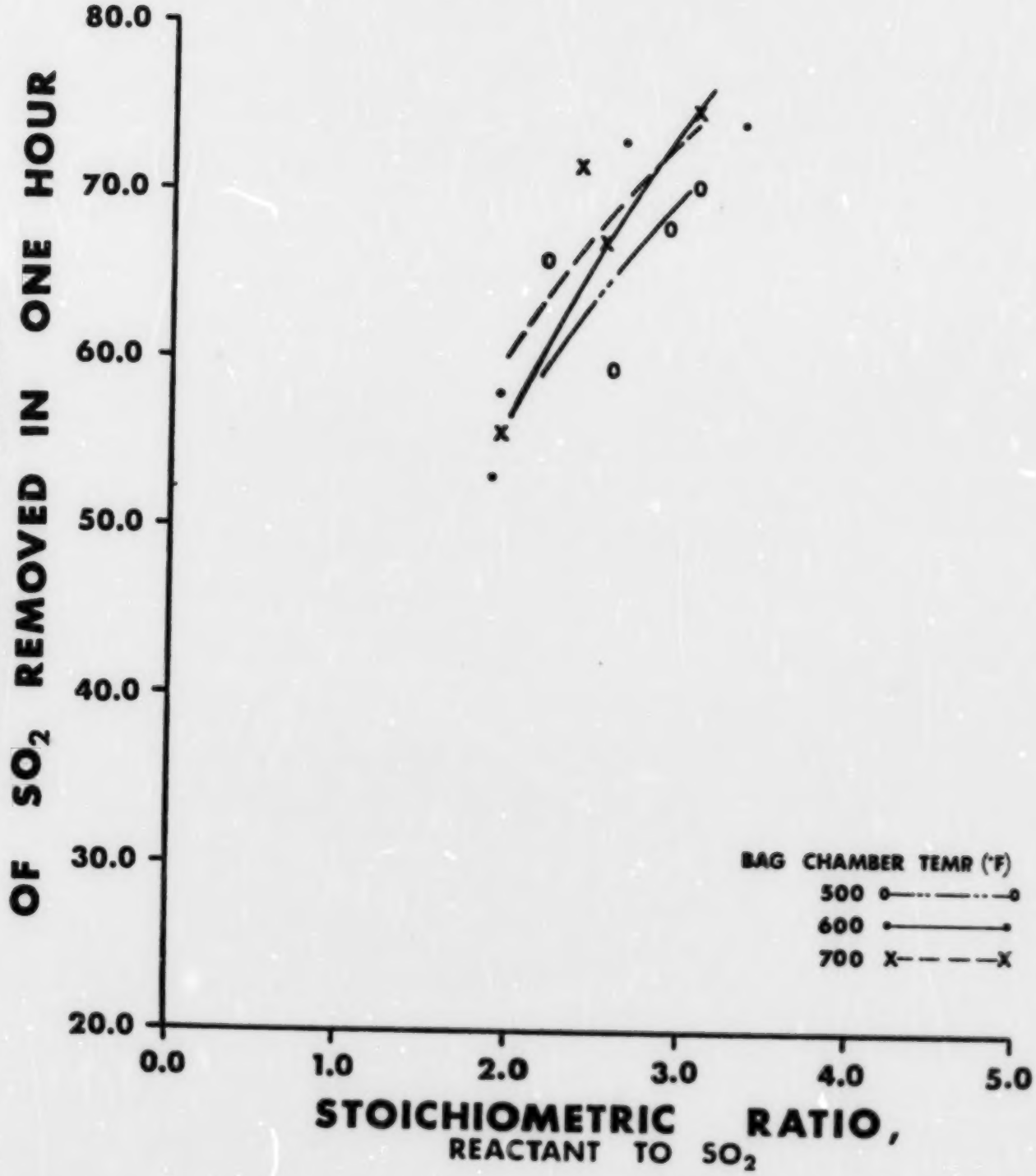
REMOVAL OF SULFUR DIOXIDE WITH SLAKED DOLOMITIC LIME AT AIR/CLOTH RATIO OF 8.0 ft./min.

Fig. 13



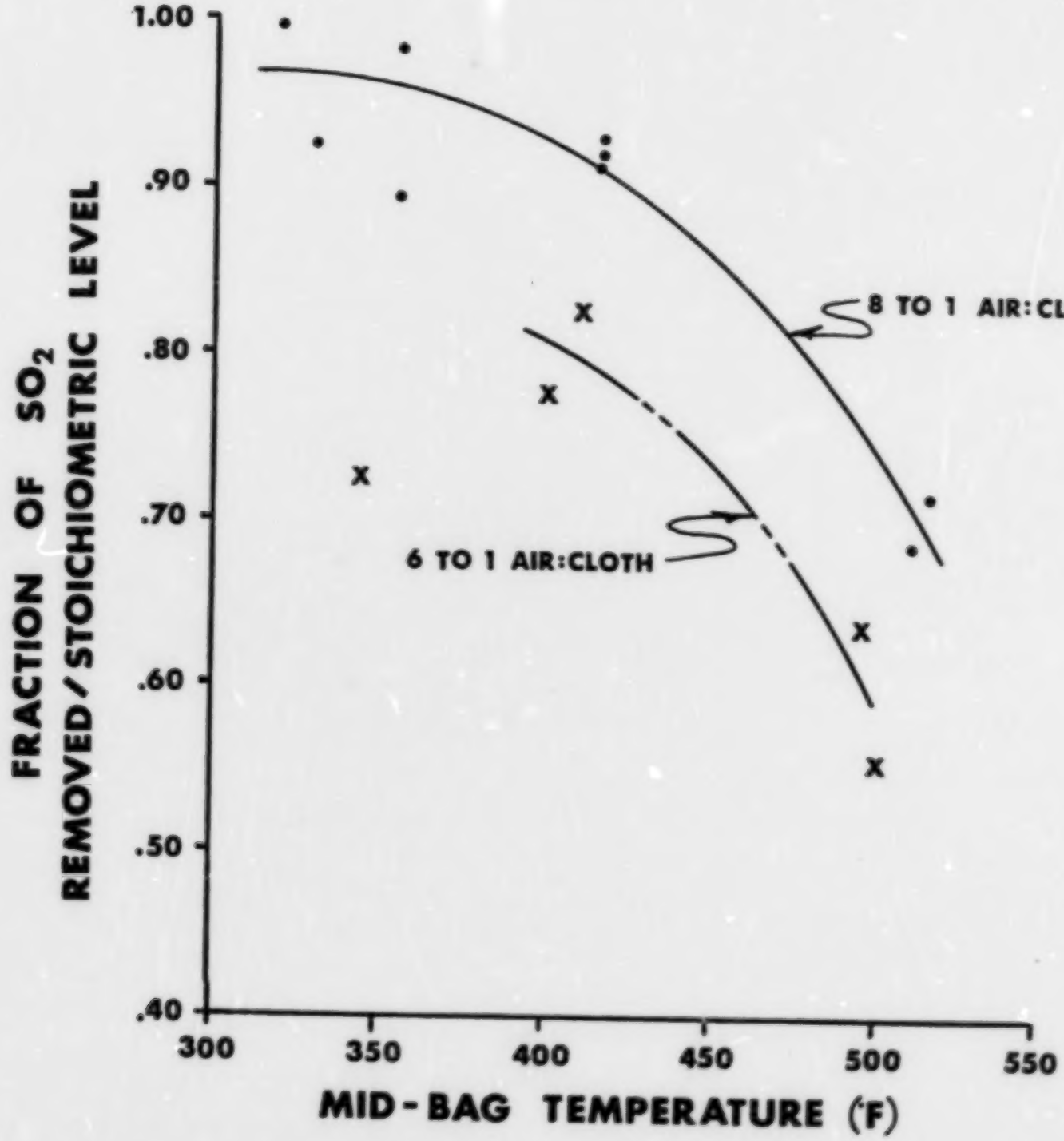
REMOVAL OF SULFUR DIOXIDE WITH SLAKED DOLOMITIC LIME (1% NaCl) AT AIR/CLOTH RATIO 8.0 ft./min.

Fig. 14



REMOVAL OF SULFUR DIOXIDE WITH MANGANESE DIOXIDE AT AIR/CLOTH RATIO OF 8.0 ft./min.

Fig. 15



EFFICIENCY OF ALKALIZED ALUMINA - SULFUR DIOXIDE REACTION VERSUS TEMPERATURE

Fig. 16

Table 5

Sulfur Dioxide Removal Efficiencies of Reactants

Reactant: Manganese Dioxide

Flow Rate:	290 cfm		385 cfm		Percentage Point Increase at 385	
Stoichiometric Level:	2.0	3.0	2.0	3.0	2.0	3.0
Bag Temperature:						
500°F	62%	72%	56%	70%	-6	-2
600°F	54	74	57	74	+3	0
700°F	58	73	60	73	+2	0

Reactant: Slaked Dolomitic Lime

Flow Rate:	290 cfm		385 cfm		Percentage Point Increase at 385	
Stoichiometric Level:	2.0	3.0	2.0	3.0	2.0	3.0
Bag Temperature:						
700°F	40%	54%	40%	52%	0	-2
800°F	52	64	55	70	+3	+6
900°F	34	49	44	60	+10	+11

Reactant: Promoted Slaked Dolomitic Lime (1% NaCl)

Flow Rate:	290 cfm		385 cfm		Percentage Point Increase at 385	
Stoichiometric Level:	2.0	3.0	2.0	3.0	2.0	3.0
Bag Temperature:						
700°F	43%	55%	44%	60%	+1	+5
800°F	51	69	55	73	+4	+4
900°F	50	65	60	69	+10	+4

Reactant: Slaked Lime

Flow Rate:	290 cfm		385 cfm		Percentage Point Increase at 385	
Stoichiometric Level:	2.0	3.0	2.0	3.0	2.0	3.0
Bag Temperature:						
700°F	46%	64%	57%	74%	+11	+10
800°F	65	78	81	91	+16	+13
900°F	52	70	65	81	+13	+11

Sulfur Dioxide Removal Efficiencies of Reactants (continued)

Reactant: Alkalized Alumina

Flow Rate:	290 cfm	385 cfm	Percentage Point Increase at 385
Stoichiometric Level:	1	1	
Bag Temperature:			
300°F	--	97%	--
400°F	80%	93	+13
500°F	60	74	+14

Reactant: Nahcolite

Flow Rate:	290 cfm	610 cfm
Stoichiometric Level:	0.8	0.7
Bag Temperature:		
300°F	59%	60%

The influence which stream flow rate has on gas absorption varies with different reactants. On the one hand, manganese dioxide is virtually unaffected by either flue gas flow rate or bag temperature. At a stoichiometric ratio of 3.0, it removes nearly the same percentage of SO_2 at 500°F as at 700°F whether the flow rate is 290 or 385 cfm.

On the other hand, flue gas flow rate has a tremendous bearing on the sorption of SO_2 by unpromoted slaked lime at all the stoichiometric

levels and reaction temperatures studied. The increase in the percentage points of SO_2 removed at the higher flow rate runs from 10 percentage points at 700°F and a 3.0 stoichiometric ratio to 16 percentage points at 800°F and a 2.0 stoichiometric ratio.

With the slaked dolomitic limes, the effect of flue gas flow rate on absorption depends on reaction temperature. The increase in flue gas flow rate significantly aided the reaction of SO_2 with the dolomitic limestones at 900°F, but had little effect at 700°F.

The flue gas flow rate studies have brought to light some interesting facts about alkalized alumina. First, alkalized alumina removed more SO_2 at the higher flow rate than at the lower. Between 400 and 500°F, for example, the increase in flue gas flow rate accounted for a 15 percentage point rise in reaction efficiency. Secondly, the removal efficiency increased with decreasing temperature in the 300 - 500°F range examined. Thirdly, alkalized alumina achieved nearly 100% reaction efficiency around 300°F. All of these are apparent from the curves in Figure 16.

In view of these findings, the data in Table 6 are of special interest. Listed under separate headings in this table are the proportions of SO_4, SO_3, and total sulfur occurring in samples of reacted material from some of the tests. Because only the weight percents of the sulfur forms are given and no other useful data such as the proportions of sodium are provided, it is rather difficult to arrive at many quantitative conclusions on the basis of this table. It would be helpful, for example, to know what other oxide components exist in the samples and in what amounts. Such information could be combined with the existing sulfur data to determine the removal efficiencies of alkalized alumina for the tests covered, and serve as a check for the removal efficiencies which are based on the alkalized alumina data in Appendix C.

In the absence of this information, crude approximations of reaction efficiency can be drawn as long as certain assumptions are made. It is very evident from Table 6 that sulfur favors the development of sulfates, not sulfites, with alkalized alumina. This fact largely suggests that Na_2SO_4 is the principle sulfur-bearing product. If it is assumed that in 100% reactant utilization, the spent dust consists completely of Na_2SO_4 and Al_2O_3 in one-to-one molar correspondence, the maximum quantity of total sulfur which can exist

in any sample is 13% by weight. Note that all of the samples listed in Table 6 contain between 8% and 11% sulfur. Under the assumed conditions, therefore, the reaction efficiencies relative to these samples are roughly between 60% and 85%. These are somewhat below the 70-100% values shown in Figure 16. Nevertheless, although based on crude techniques, they also indicate a fairly high percent of reactant used in sorbing SO_2.

Table 6

Sulfur Analysis of Reacted Dusts from Selected Alkalyzed Alumina Trials

Test No.	Sample	% SO_4	% SO_3	% Total Sulfur*
AA-1F	Fallout	25.03	1.15	8.82
	Dust Cake	31.59	0.70	10.83
AA-4	Fallout	29.81	1.00	10.25
	Dust Cake	24.63	1.25	8.73
AA-8F	Fallout	19.77	3.50	9.38
	Dust Cake	23.84	2.25	8.86
AA-10F	Fallout	27.94	0.85	9.67
	Dust Cake	32.36	0.55	11.03
AA-12F	Fallout	27.55	0.95	9.58
	Dust Cake	30.37	0.65	10.40

* Samples analyzed by Gilbert Associates, Inc., Reading, Pennsylvania, under Government direction

C. Effect of Fly Ash on SO_2 Removal

The same set of filter bags used to support SO_2 conversion can be used concurrently to control fly ash, according to experiments conducted under the Fly Ash Study series. The presence of the inert phase does not impair reactant activity; in fact, with some reactants it appears to be beneficial to it.

Table 7 lists data taken from the tests, in which mixtures of reactants and fly ash were discharged into the flue gas stream. The computed value of fly ash concentration, which is contained in the last column, was determined for each run from a knowledge of the percentage of the material in the particular mix, the quantity of mix delivered into the stream, and the stream flow rate. The stoichiometric figure was determined from the equation derived in Appendix A. As in other tests, the average concentrations of SO_2 removed were computed by approximating the integral of the appropriate curve relating SO_2 concentration to running time.

If the average removal percentages in Table 7 are compared with related values obtained from the graphs in Figures 12 to 15 in this report, it is found that many of the corresponding values coincide. This is especially true of the figures for (unpromoted) slaked lime

Table 7

Results of Fly Ash Study

Test Designation	Reactive Dust	Filtering Time	Stoich. Ratio	Mid Bag Temp.	Fly Ash Conc.	Average SO_2 Removed
UPL-FA-1F	Slaked Lime	60 min.	1.99	785°F	3.96 gr/cu. ft.	77.6%
UPL-FA-2F	" "	60 min.	2.02	795	3.99	84.5
UPD-FA-1F	Slaked Dolomitic Lime	60 min.	1.95	805	3.82	49.5
UPD-FA-2F	" " "	60 min.	2.08	800	4.05	55.9
PD-FA-1F	Slaked Lime (1% NaCl)	60 min.	1.89	800	3.71	60.0
PD-FA-2F	" " "	60 min.	1.99	800	3.91	69.7
PL-FA-1F	Slaked Lime (1% NaCl)	60 min.	2.02	825	3.91	74.0
PL-FA-2F	" " "	60 min.	1.96	800	3.84	73.3
MN-FA-1F	Manganese Dioxide	60 min.	2.16	640	4.07	78.7

and slaked dolomitic lime. The curve in Figure 12 for slaked lime at 800°F gives a value of 80% at the 2.0 stoichiometric level, which is approximately the average figure of the two lime runs conducted in the Fly Ash Series. Similarly, the 800°F curve for unpromoted dolomitic lime cuts the y-axis at 55% when the stoichiometric level is 2.0, and this figure is very close to the corresponding values obtained in Table 7.

Unfortunately, because of difficulties encountered in feeding promoted slaked lime by itself into a 385 cfm gas stream, there is no data available from earlier tests to compare with the outcomes of runs involving mixtures of this reactant and fly ash. It is apparent, nevertheless, that at 73% removal, fly ash has little or no opposing influence on the ability of the promoted lime to absorb SO_2.

Promoted slaked dolomitic lime and manganese dioxide are materials which actually demonstrated better removal percentages with fly ash in the stream than without it. The earlier curve for the promoted dolomitic lime indicated a 55% removal figure at a 2.0 stoichiometric level; the current study shows a 65% removal rate, a 10 percentage point jump. Similarly, without fly ash, MnO_2 at 600°F and 2.0 stoichiometry removed only about 60% of the SO_2 present in the gas

stream; with fly ash and under the same operational conditions , it extracted almost 80%. It should be noticed that this latter figure is closer in value to the figure obtained under similar circumstances in the Precoated Bag Study.

Despite the interesting jumps in SO_2 removal experienced by the last two materials, it is significant that with none of the reactants did fly ash prove detrimental to activity. One set of filter bags can, therefore, be used to extract both fly ash and SO_2.

D. Effect of Gas-Solids Contacting Methods on SO_2 Removal

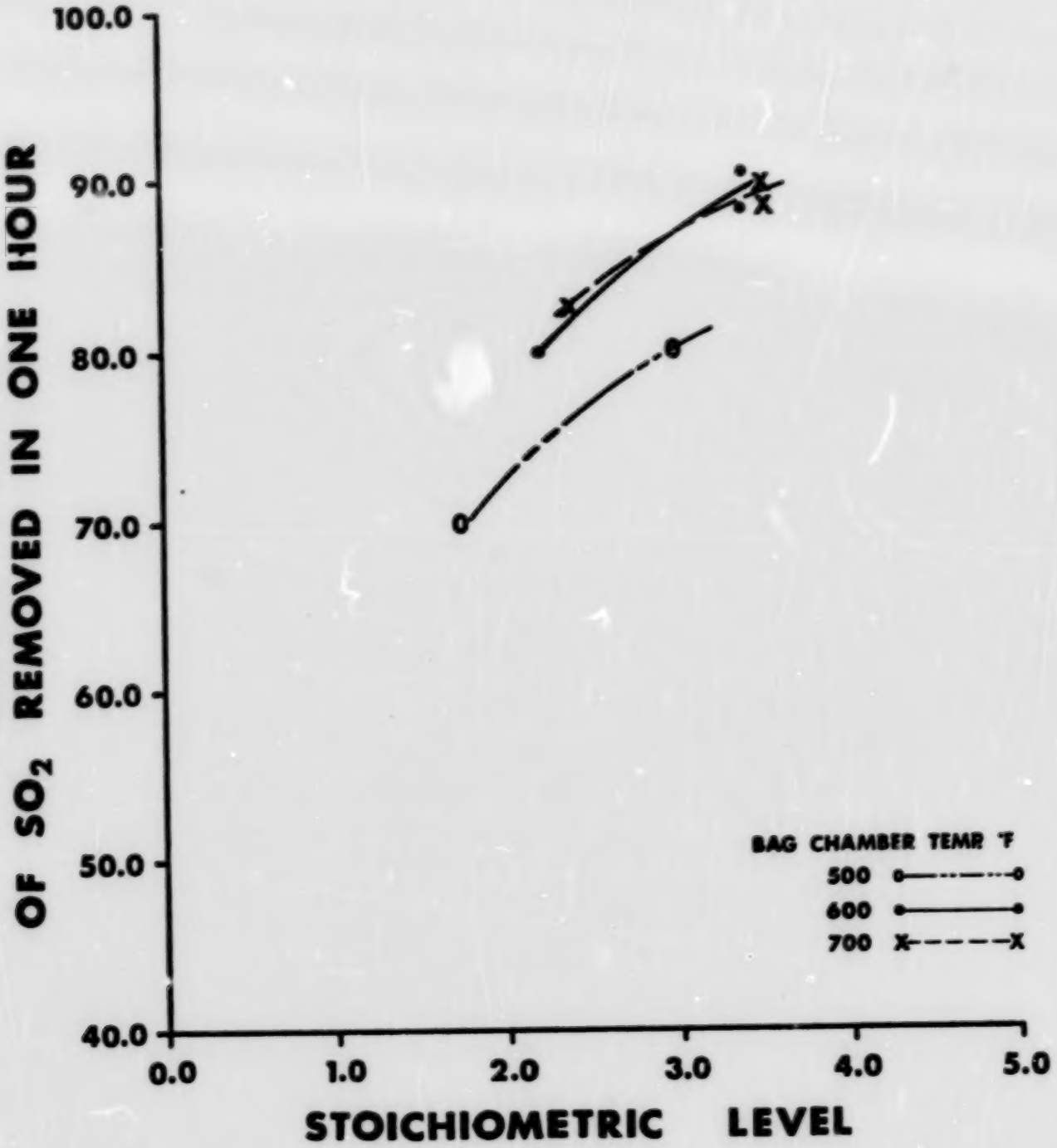
Whether precoating or continuous injection contributes more to SO_2 absorption depends on the reactant involved, according to trials run under the Precoated Bag Study. Slaked lime, when injected directly into the sulfur-bearing stream, had a relatively high capacity for absorption; however, when coated on the bags in advance of the stream, it displayed markedly little affinity for SO_2. Manganese dioxide, on the other hand, displayed a somewhat greater capacity for SO_2 when precoated on the bags than when continuously injected.

The SO_2 removal values obtained from precoating the bags with the four lime materials were generally low. In fact, with the exception

of slaked lime at twice stoichiometric requirements (Table 8), none of the calcium-based reactants removed more than 15% of the gas, despite changes in stream temperature and stoichiometric ratio. At first it was thought that these low values stemmed from the physical state of the reactant on the bags; that is, the layer of deposited material was thought to be too thin to kinetically favor reaction with the fast-moving SO_2 molecules. Further investigation, however, disproved this notion; the answer was found to be more chemical than physical. Opening the door of the filter bag chamber after several disappointing runs disclosed a thick, heavy cementitious deposit on the bags that obviously had not responded well to cleaning. An analysis of this material showed it to consist largely of carbonates. Since hydrated lime is very reactive toward both CO_2 and SO_2 between 700°F and 900°F, and because calcium carbonate is known not to be receptive to SO_2 much below 1000°F, it is evident that the reactant had become a carbonate prior to making contact with the sulfur-bearing stream. Apparently this change came about while the material was being laid over the bags. Its exposure to CO_2 in the gas stream during this time had caused the lime reactant to convert to a chemical form more stable in the presence of SO_2. Thus, the precoating method shows considerably less removal with the hydrated limes than the continuous injection method shows.

Although deposited on the bags in the same manner as the limes, manganese dioxide gave unusually high SO_2 removal values, as indicated in Table 8 and Figure 17. (Manganese dioxide, unlike the limes, is not particularly receptive to CO_2 or other products of natural gas combustion). If figures in Table 8 are compared with values taken from corresponding continuous-coating tests, it is found that MnO_2 extracted slightly more SO_2 per stoichiometry when deposited on the bags ahead of the gas stream, than when discharged directly into the stream and subsequently deposited on the bags.

Because the precise amount of reactant available for combination with SO_2 is known, the precoated study on MnO_2 lends itself to a meaningful comparison between the sulfur content of the dust cake as determined by chemical analysis and as computed from information obtained in Table 8. According to the table, for example, 2.91 parts (by mole) of MnO_2 combined with 0.81 parts of SO_2 in test MN-5FB. Assuming the product of the MnO_2-SO_2 reaction to be $MnSO_4$, the dust cake at the end of the run should contain 0.81 parts of $MnSO_4$ for each (2.91 - 0.81) or 2.10 parts MnO_2. The quantity of sulfur in this mixture was calculated to be 8.5% by weight. Chemical analysis (Appendix D) of the dust cake (and fallout) indicated an



REMOVAL OF SULFUR DIOXIDE WITH MANGANESE DIOXIDE ON BAG SURFACES AT AIR/CLOTH = 8.0 ft./min.

Fig. 17

8.8% sulfur content. Similarly, analysis of the expended dust cake of test MN-4FB shows a 7.5% sulfur determination; on the basis of removal test data, this quantity of sulfur should be 8.1%. There appears to be good correlation in the sulfur contents of the samples as determined from chemical analysis and reasoning from removal data.

Table 8

Results of Precoated Bag Study

Test Designation	Reactive Dust	Filtering Time	Stoich. Ratio	Mid-Bag Temp.	Flue Gas Flow Rate	Average SO_2 Removal
UPL-1FB	Slaked Lime	60 min.	2.28	695°F	385 cfm	27.9%
UPL-2FB	" "	"	2.19	785°F	"	54.5%
UPL-3FB	" "	"	2.12	800°F	"	33.4%
UPL-4FB	" "	"	2.09	895°F	"	26.7%
UPL-5FB	" "	"	1.80	900°F	"	30.7%
MN-1FB	Manganese Dioxide	"	3.36	600°F	"	90.4%
MN-2FB	"	"	3.35	600°F	"	88.6%
MN-3FB	"	"	3.49	700°F	"	88.4%
MN-4FB	"	"	3.47	695°F	"	89.9%
MN-5FB	"	"	2.91	500°F	"	80.5%
MN-6FB	"	"	1.74	500°F	"	70.4%
MN-7FB	"	"	2.20	600°F	"	80.2%
MN-8FB	"	"	2.35	700°F	"	82.9%
MN-9B	"	"	1.96	615°F	290 cfm	46.4%
MN-10B	"	"	2.30	705°F	"	55.2%

APPENDIX A

Derivation of Stoichiometry Equation

APPENDIX A

Derivation of Stoichiometry Equation

The equation for calculating the stoichiometric ratio of reactant to SO_2 was derived in the following way. If the flue gas stream flowing at a volume rate of f cubic feet/min. contains c parts per million of SO_2 at temperature T and atmospheric pressure, the volume occupied by the SO_2 alone during time period t under these conditions would be equal to cft x 10^{-6}. On the assumption that the gas is ideal--and since the pressure is near one atmosphere, this assumption is realistic--the volume of SO_2 at 32°F is:

$$\frac{4.60 \times 10^{-4} \text{ cft}}{T + 460}$$

The density of SO_2 at this temperature is 0.1827 lbs/cu. ft.* Thus the weight of SO_2 in grams is determined by the relation:

$$\frac{\text{cft } (4.60 \times 10^{-4}) \ (453.6) \ (0.1827)}{T + 460} = \frac{3.81 \times 10^{-2} \text{ cft}}{T + 460}$$

The final form of this equation is derived from simple chemical balancing techniques. Suppose the additive contains only one reactive component, the other components being relatively nonparticipatory. When SO_2 completely reacts with the solid additive, the reaction follows the chemical relation:

$$aA + bSO_2 + cC + \ldots\ldots = \delta\tau + \lambda\theta \ \ldots\ldots$$

where A represents the reacting component in the additive, C may be <u>either</u> a nonparticipating component of the solid additive or a participating component in the gas stream, and τ and θ are reaction products. The amount of component A in grams just necessary to react entirely with x grams of SO_2 is equal to

$$\frac{amx}{64.0\ b}$$

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*<u>Handbook of Chemistry and Physics</u>, 44th Edition, Chemical Rubber Publishing Co., Cleveland, Ohio, p. 2142.

where m is the gram "molecular" weight of A. If the additive contains n% of A by weight, then the total weight of the additive necessary to combine with the SO_2 is $\frac{100\ amx}{64.0\ nb}$.

In the principal formula above,

$$X = \frac{3.81 \times 10^{-2}\ cft}{T + 460} \quad \text{and} \quad M = \frac{100\ am}{nb}$$

By definition, the stoichiometric level of additive is the ratio of the weight of material, W_r, actually discharged into the stream to the amount required for a theoretically complete reaction, or:

$$\frac{W_r}{\frac{100\ amx}{64.0\ nb}} = \frac{W_r\ (T + 460)\ (64.0)}{3.81 \times 10^{-2}\ cft\ M} = \frac{W_r\ (T + 460)}{5.95 \times 10^{-4}\ cft\ M}$$

The values of M for manganese dioxide, activated alkalized alumina, slaked lime, and Nahcolite were based on these equivalents:

(a) one molecule of MnO_2 for each molecule of SO_2

(b) two molecules of $NaAlO_2$ for each molecule of SO_2

(c) one molecule of CaO for each one of SO_2

(d) two molecules of $NaHCO_3$ for each molecule of SO_2

According to the chemical analyses of the raw additives, manganese dioxide is 95% MnO_2 by weight, alkalized alumina is 100% $NaAlO_2$, slaked lime is 70% CaO, and Nahocolite is 70% $NaHCO_3$. Therefore, M for manganese dioxide is 91.3; for alkalized alumina, 240.0; slaked lime, 80.1, and for Nahcolite 240%.

For additives containing two or more reactive components, which act on the SO_2 independently of one another, (e.g. dolomite) the gram molecular weight is represented by the equation:

$$M = \frac{100}{\sum_{i=1}^{k} \left[\left(\frac{b}{a_i} \right) \frac{n_i}{m_i} \right]}$$

where: k = the total number of different types of reactive components present in the dust

$\frac{b}{a_i}$ = the number of parts of SO_2 per part of component i necessary for a complete reaction

n_i = the weight percent of component i in the dust

m_i = the gram formula weight of component i

This equation is easily derived with reasoning similar to that used in deriving the equation for one component additives. Suppose the dust contains n_1 percent by weight of reactive oxide component 1, which has a gram formula weight (gfw) of m_1, n_2 percent of reactive component 2 with gfw of m_2,...and n_k percent of reactant k, with gfw of m_k. In 100 grams of additive, the amount of SO_2 by weight, X_i, which will react with component i is given by:

$$X_i = \frac{b}{a_i} \quad \frac{64.0\ n_i}{m_i}$$

The total weight of SO_2 which will react with 100 grams of the additive is merely the sum of the weights reacting with the additive's individual compoents. Hence:

$$X_{total} = \sum_{i=1}^{k} X_i = 64.0 \sum_{i=1}^{k} \left[\left(\frac{b}{a} \right)_i \frac{n_i}{m_i} \right]$$

The gram equivalent weight of the additive is determined by the relation:

$$\frac{100}{M} \quad \frac{X\ total}{64.0} = \sum_{i=1}^{k} \left[\left(\frac{b}{a} \right)_i \frac{n_i}{m_i} \right]$$

or

$$M = \frac{100}{\sum_{i=1}^{k} \left[\left(\frac{b}{a} \right) \frac{n_i}{m_i} \right]}$$

Dolomitic limes may be regarded as containing two reactive species, CaO and MgO. The unpromoted lime was found to consist of 44 (weight) % CaO ($m_{CaO} = 56.0$) and 31% MgO ($m_{MgO} = 40.3$), and the promoted lime to contain 43% CaO and 30% MgO. Substituting the appropriate values in the equation derived nets a figure of 65.3 for unpromoted dolomite and 65.0 for the promoted material. These values of M are inserted into the relation:

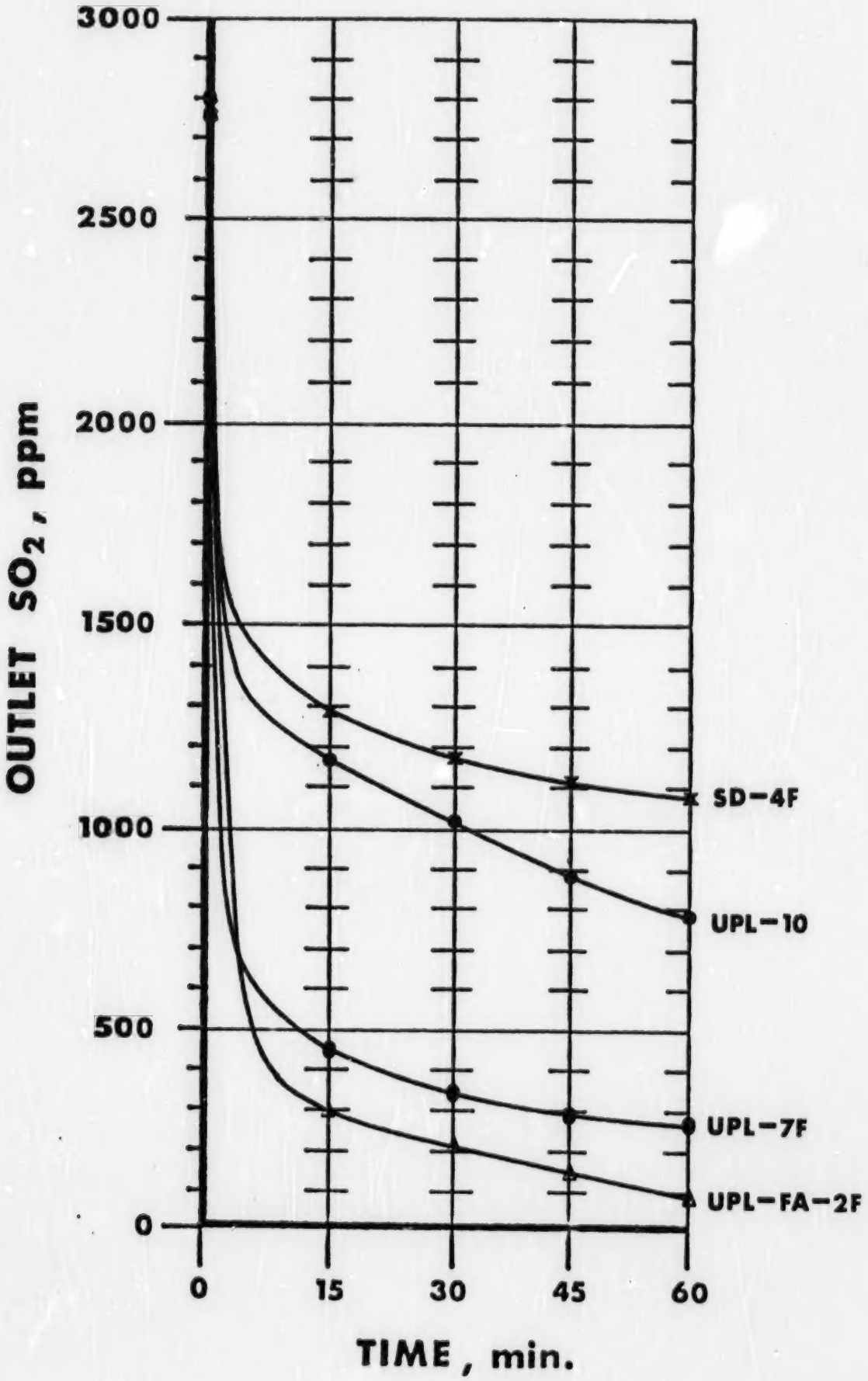
$$S = \frac{W_r\ (T + 460)}{5.95 \times 10^{-4}\ \text{cft}\ M}$$

to determine the stoichiometric level of the dolomites in the SO_2 containing gas stream during the filtering cycle.

APPENDIX B

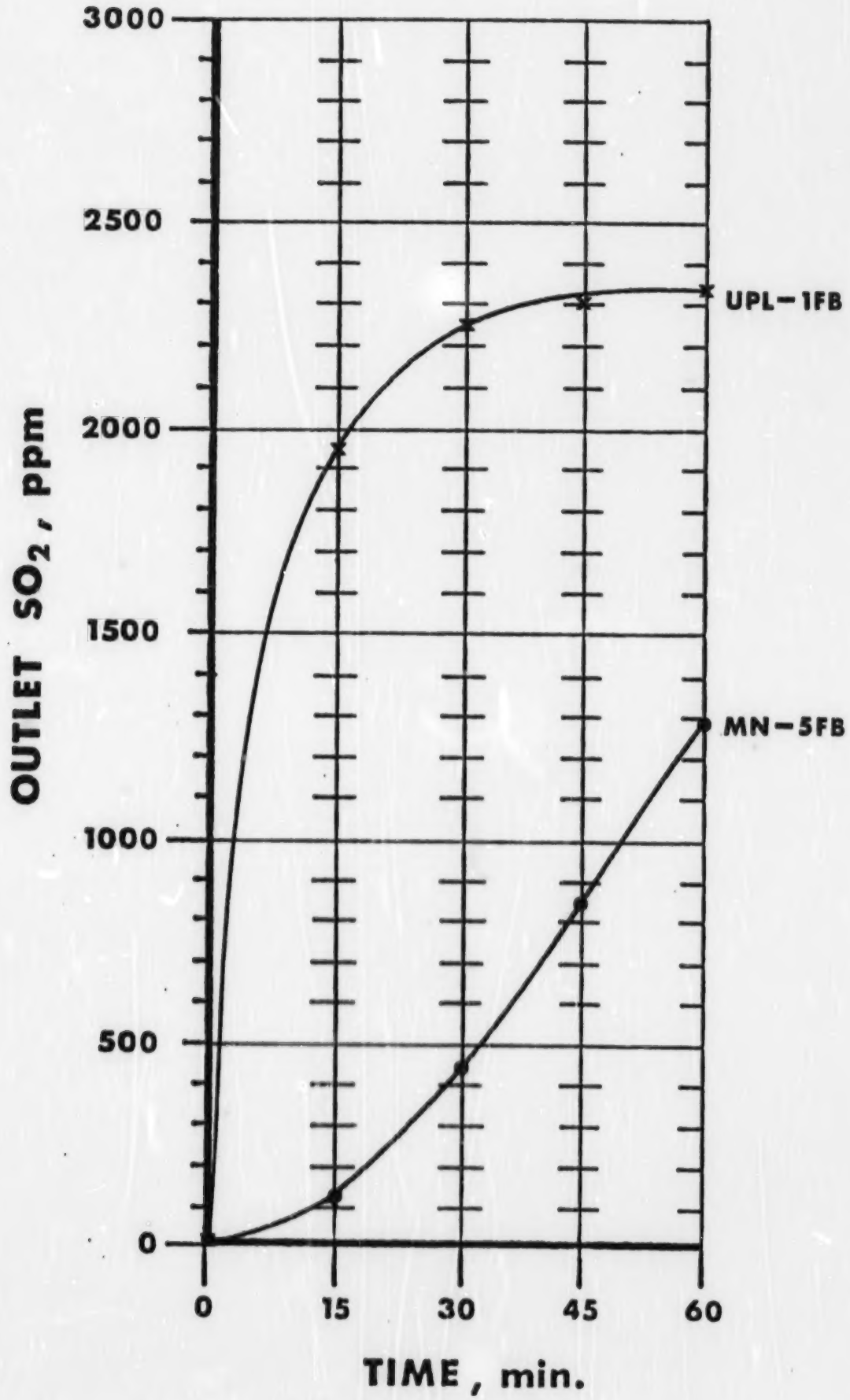
Representative Test Data

TYPICAL BREAKTHROUGH CURVES
CONTINUOUS REACTANT INJECTION

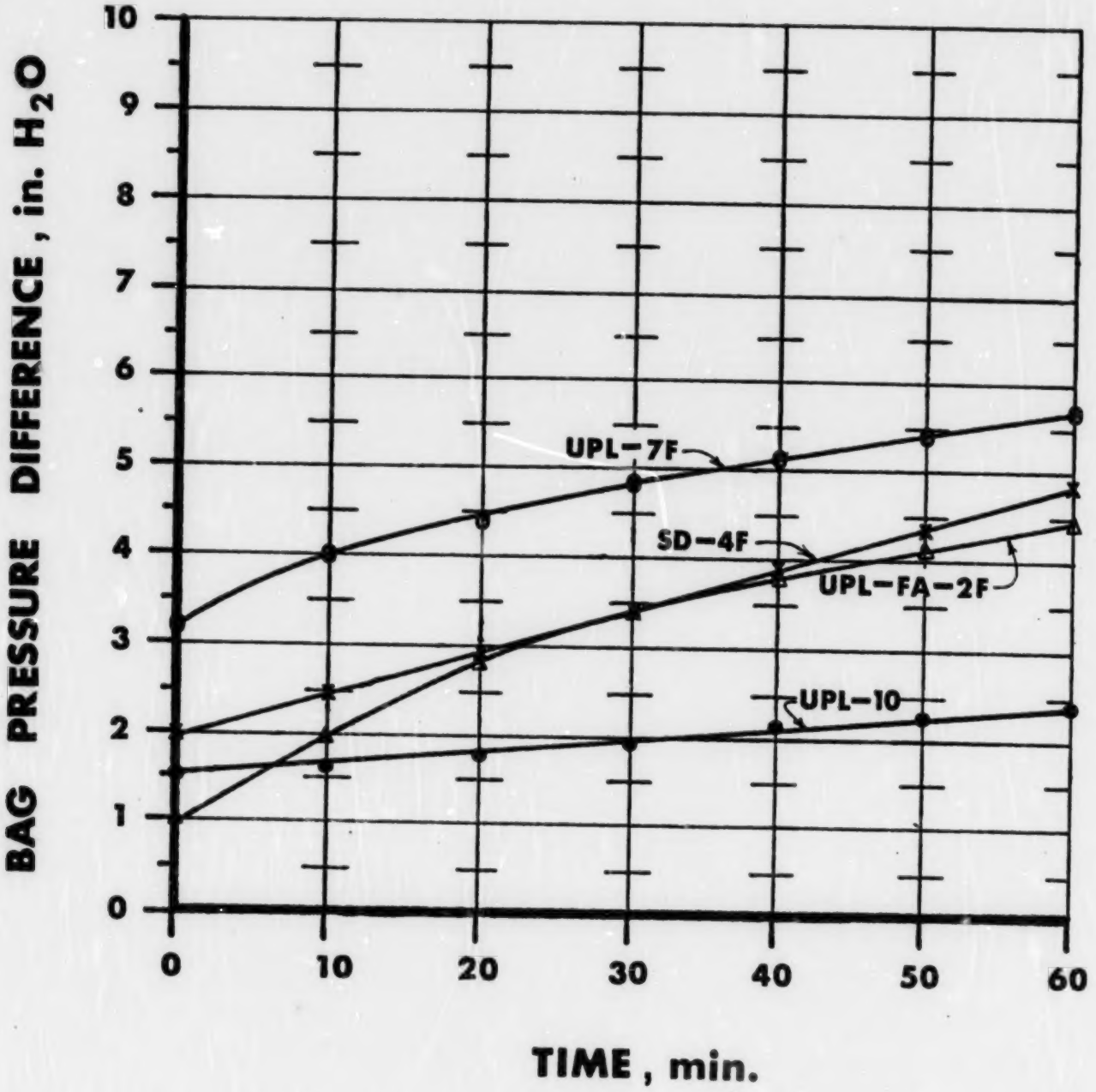


TYPICAL BREAKTHROUGH CURVES

PRECOATING



TYPICAL BAG PRESSURE LOSS CURVES



APPENDIX C

Data

ADDITIVE STUDY

Test Designation	Reactant Used	Test Interval	Gas Flow Rate	Stoich. Ratio	Bag Temperature			Pressure Drop		SO_2 Conc.		Average SO_2 Removal Over Interval
					Bottom	Middle	Top	Average	Final	To Bags	Removed From Flue Gases	
UPL-3	Slaked Lime	60 Min.	290 cfm	2.61	1015°F	920°F	815°F	1.3 in. H_2O	1.6 in. H_2O	2790 ppm	1540 ppm	55%
UPL-4	"	"	"	2.24	1070°F	955°F	850°F	2.2 in. H_2O	2.7 in. H_2O	2810 ppm	1330 ppm	47%
UPL-5	"	"	"	2.14	1025°F	915°F	825°F	2.0 in. H_2O	2.6 in. H_2O	2740 ppm	1460 ppm	53%
UPL-6	"	"	"	1.54	885°F	795°F	720°F	1.3 in. H_2O	1.8 in. H_2O	2840 ppm	1690 ppm	60%
UPL-7	"	"	"	2.52	900°F	790°F	700°F	No Data		2820 ppm	1980 ppm	70%
UPL-8	"	"	"	1.93	760°F	695°F	650°F	1.9 in. H_2O	2.5 in. H_2O	2775 ppm	1255 ppm	45%
UPL-9	"	"	"	2.45	750°F	700°F	645°F	2.1 in. H_2O	2.7 in. H_2O	2810 ppm	1605 ppm	57%
UPL-10	"	"	"	1.80	855°F	790°F	715°F	2.0 in. H_2O	2.4 in. H_2O	2750 ppm	1600 ppm	58%
UPL-11	"	"	"	2.24	875°F	800°F	725°F	1.8 in. H_2O	2.1 in. H_2O	2750 ppm	2055 ppm	75%
UPL-12	"	"	"	2.15	775°F	710°F	655°F	2.0 in. H_2O	2.7 in. H_2O	2840 ppm	1580 ppm	56%
UPL-13	"	"	"	2.61	845°F	795°F	730°F	2.5 in. H_2O	2.9 in. H_2O	2870 ppm	1970 ppm	70%
UPL-14	"	"	"	1.50	890°F	795°F	730°F	2.6 in. H_2O	2.7 in. H_2O	2810 ppm	1055 ppm	38%
UPL-15	"	"	"	1.24	885°F	790°F	710°F	1.7 in. H_2O	2.0 in. H_2O	2840 ppm	930 ppm	33%
UPL-16	"	"	"	3.08	900°F	800°F	730°F	2.1 in. H_2O	2.6 in. H_2O	2820 ppm	2100 ppm	74%
UPL-17	"	"	"	3.29	910°F	805°F	730°F	2.3 in. H_2O	2.6 in. H_2O	2830 ppm	2255 ppm	80%
UPL-18	"	"	"	3.12	1000°F	900°F	800°F	2.0 in. H_2O	2.4 in. H_2O	2840 ppm	2000 ppm	70%
UPL-19	"	"	"	3.19	750°F	705°F	660°F	2.0 in. H_2O	2.7 in. H_2O	2850 ppm	1540 ppm	54%
UPL-20	"	"	"	3.19	725°F	690°F	650°F	2.0 in. H_2O	2.1 in. H_2O	2850 ppm	1885 ppm	66%

ADDITIVE STUDY

Test Designation	Reactant Used	Test Interval	Gas Flow Rate	Stoich. Ratio	Bag Temperature			Pressure Drop		SO_2 Conc.		Average SO_2 Removal Over Interval
					Bottom	Middle	Top	Average	Final	To Bags	Removed From Flue Gases	
UPL-21	Slaked Lime	60 Min.	290 cfm	3.59	965°F	890°F	815°F	2.7 in. H_2O	3.4 in. H_2O	2840 ppm	2230 ppm	78%
UPL-22	"	"	"	2.63	970°F	890°F	800°F	2.1 in. H_2O	2.6 in. H_2O	2800 ppm	1810 ppm	65%
UPL-23	"	"	"	2.26	990°F	895°F	795°F	1.8 in. H_2O	2.3 in. H_2O	2800 ppm	1775 ppm	63%
PL-1	Slaked Lime (1% NaCl)	"	"	2.64	1000°F	900°F	815°F	.9 in. H_2O	1.3 in. H_2O	2810 ppm	1815 ppm	65%
PL-2	"	"	"	2.25	1015°F	895°F	800°F	1.3 in. H_2O	1.7 in. H_2O	2800 ppm	1720 ppm	62%
PL-3	"	"	"	3.69	1015°F	900°F	800°F	1.6 in. H_2O	2.1 in. H_2O	2825 ppm	1890 ppm	67%
PL-4	"	"	"	2.62	915°F	810°F	740°F	1.4 in. H_2O	1.9 in. H_2O	2790 ppm	2040 ppm	73%
PL-5	"	"	"	2.39	905°F	810°F	740°F	1.5 in. H_2O	2.0 in. H_2O	2800 ppm	2050 ppm	73%
PL-6	"	"	"	2.48	775°F	695°F	655°F	1.5 in. H_2O	2.0 in. H_2O	2700 ppm	1685 ppm	62%
PL-7	"	"	"	2.43	770°F	700°F	660°F	1.6 in. H_2O	2.1 in. H_2O	2780 ppm	1730 ppm	62%
PL-8	"	"	"	1.28	890°F	800°F	730°F	1.1 in. H_2O	1.4 in. H_2O	2800 ppm	1380 ppm	49%
PL-9	"	"	"	1.50	900°F	800°F	730°F	1.9 in. H_2O	2.3 in. H_2O	2790 ppm	1540 ppm	55%
PL-10	"	"	"	3.34	890°F	800°F	740°F	1.6 in. H_2O	2.0 in. H_2O	2790 ppm	2350 ppm	84%
PL-11	"	"	"	3.64	900°F	805°F	745°F	1.8 in. H_2O	2.5 in. H_2O	2800 ppm	2390 ppm	85%
PL-12	"	"	"	3.78	975°F	915°F	825°F	2.0 in. H_2O	2.5 in. H_2O	2760 ppm	2120 ppm	77%
PL-13	"	"	"	3.10	950°F	910°F	825°F	2.0 in. H_2O	2.7 in. H_2O	2720 ppm	2050 ppm	74%
PL-14	"	"	"	2.68	735°F	705°F	665°F	2.0 in. H_2O	3.1 in. H_2O	2800 ppm	1975 ppm	71%
PL-15	"	"	"	2.44	695°F	695°F	660°F	2.1 in. H_2O	3.0 in. H_2O	2800 ppm	1835 ppm	66%

ADDITIVE STUDY

Test Designation	Reactant Used	Test Interval	Gas Flow Rate	Stoich. Ratio	Bag Temperature			Pressure Drop		SO_2 Conc.		Average SO_2 Removal Over Interval
					Bottom	Middle	Top	Average	Final	To Bags	Removed From Flue Gases	
PL-16	Slaked Lime (1% NaCl)	60 Min.	290 cfm	3.39	720°F	700°F	670°F	2.3 in. H_2O	3.3 in. H_2O	2790 ppm	1880 ppm	67%
PL-17	"	"	"	3.35	725°F	705°F	670°F	2.7 in. H_2O	3.8 in. H_2O	2760 ppm	1790 ppm	65%
PL-18	"	"	"	3.40	845°F	805°F	760°F	3.2 in. H_2O	4.7 in. H_2O	2790 ppm	2350 ppm	84%
PL-19	"	"	"	3.53	855°F	810°F	755°F	2.6 in. H_2O	3.8 in. H_2O	2775 ppm	2285 ppm	82%
PL-1C	"	"	"	1.86	975°F	915°F	815°F	2.1 in. H_2O	3.2 in. H_2O	2775 ppm	1830 ppm	66%
PL-2C	"	"	"	1.90	985°F	910°F	835°F	3.2 in. H_2O	4.2 in. H_2O	2750 ppm	1585 ppm	58%
PL-3C	"	"	"	1.66	865°F	795°F	740°F	2.0 in. H_2O	3.1 in. H_2O	2780 ppm	1905 ppm	68%
PL-4C	"	"	"	2.02	865°F	795°F	740°F	3.2 in. H_2O	4.2 in. H_2O	2780 ppm	1935 ppm	70%
PL-5C	"	"	"	1.99	760°F	705°F	665°F	2.6 in. H_2O	3.8 in. H_2O	2760 ppm	1440 ppm	52%
PL-6C	"	"	"	1.98	745°F	695°F	660°F	3.6 in. H_2O	4.8 in. H_2O	2810 ppm	1480 ppm	53%
SD-1	Slaked Dolomitic Lime	"	"	3.16	970°F	890°F	805°F	1.3 in. H_2O	2.0 in. H_2O	2800 ppm	1540 ppm	55%
SD-2	"	"	"	2.36	980°F	890°F	805°F	1.7 in. H_2O	2.2 in. H_2O	2820 ppm	1060 ppm	38%
SD-3	"	"	"	2.05	975°F	890°F	805°F	1.7 in. H_2O	2.3 in. H_2O	2810 ppm	1030 ppm	37%
SD-4	"	"	"	2.34	865°F	790°F	730°F	2.3 in. H_2O	2.9 in. H_2O	2790 ppm	1595 ppm	57%
SD-5	"	"	"	2.11	870°F	795°F	740°F	2.2 in. H_2O	2.8 in. H_2O	2775 ppm	1470 ppm	53%
SD-6	"	"	"	2.05	755°F	700°F	660°F	2.3 in. H_2O	3.0 in. H_2O	2770 ppm	1165 ppm	42%
SD-7	"	"	"	2.33	755°F	705°F	670°F	2.4 in. H_2O	3.0 in. H_2O	2790 ppm	1190 ppm	43%

ADDITIVE STUDY

Test Designation	Reactant Used	Test Interval	Gas Flow Rate	Stoich. Ratio	Bag Temperature			Pressure Drop		SO_2 Conc.		Average SO_2 Removal Over Interval
					Bottom	Middle	Top	Average	Final	To Bags	Removed From Flue Gases	
SD-8	Slaked Dolomitic Lime	60 min.	290 cfm	0.94	840°F	790°F	740°F	2.0 in. H_2O	2.6 in. H_2O	2790 ppm	900 ppm	32%
SD-9	"	"	"	1.10	855°F	800°F	745°F	2.0 in. H_2O	2.6 in. H_2O	2800 ppm	900 ppm	32%
SD-10	"	"	"	3.09	860°F	795°F	740°F	2.4 in. H_2O	3.1 in. H_2O	2770 ppm	1890 ppm	68%
SD-11	"	"	"	3.08	860°F	795°F	735°F	2.3 in. H_2O	3.0 in. H_2O	2820 ppm	1740 ppm	63%
SD-12	"	"	"	2.96	860°F	800°F	740°F	2.5 in. H_2O	3.2 in. H_2O	2830 ppm	1710 ppm	62%
SD-13	"	"	"	2.89	970°F	895°F	815°F	2.2 in. H_2O	2.6 in. H_2O	2750 ppm	1240 ppm	45%
SD-14	"	"	"	2.87	975°F	885°F	800°F	2.1 in. H_2O	2.7 in. H_2O	2770 ppm	1370 ppm	49%
SD-15	"	"	"	2.59	750°F	695°F	660°F	2.3 in. H_2O	3.5 in. H_2O	2770 ppm	1565 ppm	56%
SD-16	"	"	"	3.12	740°F	695°F	665°F	2.3 in. H_2O	3.2 in. H_2O	2790 ppm	1435 ppm	51%
PD-1	Slaked Dolomitic Lime (1% NaCl)	"	"	3.34	970°F	910°F.	840°F	1.8 in. H_2O	2.7 in. H_2O	2825 ppm	1930 ppm	68%
PD-2	"	"	"	2.58	965°F	895°F	825°F	3.1 in. H_2O	4.1 in. H_2O	2800 ppm	1650 ppm	59%
PD-3	"	"	"	2.42	975°F	915°F	845°F	4.5 in. H_2O	6.1 in. H_2O	2770 ppm	1615 ppm	58%
PD-4	"	"	"	2.29	980°F	905°F	820°F	2.3 in. H_2O	2.9 in. H_2O	2780 ppm	1500 ppm	54%
PD-5	"	"	"	2.50	980°F	795°F	720°F	2.1 in. H_2O	2.8 in. H_2O	2580 ppm	1475 ppm	63%
PD-6	"	"	"	2.53	890°F	795°F	710°F	2.0 in. H_2O	2.3 in. H_2O	2780 ppm	1505 ppm	54%
PD-7	"	"	"	2.48	890°F	800°F	710°F	2.1 in. H_2O	2.5 in. H_2O	2800 ppm	1670 ppm	60%
PD-8	"	"	"	2.41	750°F	695°F	650°F	3.0 in. H_2O	3.9 in. H_2O	2780 ppm	1330 ppm	48%
PD-9	"	"	"	2.36	750°F	705°F	660°F	2.7 in. H_2O	3.4 in. H_2O	2760 ppm	1350 ppm	49%
PD-10	"	"	"	1.27	850°F	800°F	730°F	2.4 in. H_2O	3.1 in. H_2O	2780 ppm	795 ppm	29%

ADDITIVE STUDY

Test Designation	Reactant Used	Test Interval	Gas Flow Rate	Stoich. Ratio	Bag Temperature			Pressure Drop		SO_2 Conc.		Average SO_2 Removal Over Interval
					Bottom	Middle	Top	Average	Final	To Bags	Removed From Flue Gases	
PD-11	Slaked Dolomitic Lime (1% NaCl)	60 min.	290 cfm	1.17	840°F	795°F	735°F	2.4 in. H_2O	3.0 in. H_2O	2770 ppm	780 ppm	28%
PD-12	"	"	"	1.09	840°F	795°F	735°F	2.7 in. H_2O	3.5 in. H_2O	2750 ppm	915 ppm	33%
PD-13	"	"	"	2.81	830°F	790°F	730°F	3.9 in. H_2O	5.9 in. H_2O	2775 ppm	1940 ppm	70%
PD-14	"	"	"	3.11	840°F	805°F	745°F	4.3 in. H_2O	5.9 in. H_2O	2775 ppm	1930 ppm	69%
PD-15	"	"	"	3.01	845°F	800°F	735°F	3.7 in. H_2O	5.3 in. H_2O	2790 ppm	1820 ppm	65%
PD-16	"	"	"	3.01	730°F	695°F	660°F	3.8 in. H_2O	5.7 in. H_2O	2790 ppm	1535 ppm	55%
PD-17	"	"	"	3.04	955°F	900°F	815°F	4.2 in. H_2O	5.9 in. H_2O	2780 ppm	1825 ppm	66%
PD-18	"	"	"	3.09	965°F	910°F	830°F	3.5 in. H_2O	4.9 in. H_2O	2750 ppm	1840 ppm	67%
UPL-1C	Slaked Lime	"	"	3.00	980°F	900°F	820°F	.9 in. H_2O	1.5 in. H_2O	2735 ppm	1975 ppm	72%
UPL-2C	"	"	"	2.66	975°F	900°F	825°F	1.6 in. H_2O	2.4 in. H_2O	2740 ppm	1845 ppm	67%
UPL-3C	"	"	"	2.06	860°F	805°F	745°F	2.0 in. H_2O	2.9 in. H_2O	2790 ppm	1940 ppm	69%
UPL-4C	"	"	"	1.64	840°F	800°F	745°F	1.9 in. H_2O	2.6 in. H_2O	2780 ppm	1590 ppm	57%
UPL-5C	"	"	"	1.67	730°F	700°F	670°F	1.9 in. H_2O	2.7 in. H_2O	2775 ppm	1020 ppm	37%
UPL-6C	"	"	"	2.00	725°F	700°F	665°F	3.5 in. H_2O	5.3 in. H_2O	2770 ppm	1265 ppm	46%
MN-1	Manganese Dioxide	"	"	2.05	665°F	610°F	575°F	.7 in. H_2O	1.0 in. H_2O	2760 ppm	1380 ppm	50%
MN-2	"	48 min.	"	1.91	670°F	610°F	575°F	1.1 in. H_2O	1.3 in. H_2O	2770 ppm	1435 ppm	52%
MN-3	"	60 min.	"	2.44	795°F	705°F	660°F	1.8 in. H_2O	2.2 in. H_2O	2770 ppm	1820 ppm	66%
MN-4	"	"	"	2.46	800°F	710°F	665°F	2.0 in. H_2O	2.6 in. H_2O	2790 ppm	1900 ppm	68%
MN-5	"	"	"	2.28	550°F	510°F	495°F	1.9 in. H_2O	2.4 in. H_2O	2790 ppm	1825 ppm	65%

ADDITIVE STUDY

Test Designation	Reactant Used	Test Interval	Gas Flow Rate	Stoich. Ratio	Bag Temperature			Pressure Drop		SO_2 Conc.		Average SO_2 Removal Over Interval
					Bottom	Middle	Top	Average	Final	To Bags	Removed From Flue Gases	
MN-6	Manganese Dioxide	60 min.	290 cfm	2.12	560°F	505°F	500°F	2.5 in. H_2O	2.6 in. H_2O	2800 ppm	1835 ppm	65%
MN-7	"	"	"	1.36	660°F	600°F	570°F	2.0 in. H_2O	2.3 in. H_2O	2775 ppm	970 ppm	35%
MN-8	"	"	"	1.15	660°F	595°F	570°F	2.0 in. H_2O	2.3 in. H_2O	2745 ppm	1020 ppm	37%
MN-9	"	"	"	2.77	660°F	595°F	570°F	2.5 in. H_2O	2.9 in. H_2O	2765 ppm	1925 ppm	70%
MN-10	"	"	"	2.70	660°F	600°F	570°F	2.3 in. H_2O	3.0 in. H_2O	2760 ppm	1880 ppm	68%
MN-11	"	"	"	2.76	755°F	690°F	645°F	2.6 in. H_2O	3.1 in. H_2O	2790 ppm	1950 ppm	70%
MN-12	"	"	"	2.90	780°F	700°F	655°F	2.7 in. H_2O	3.1 in. H_2O	2790 ppm	1920 ppm	69%
MN-13	"	"	"	3.07	540°F	500°F	490°F	2.5 in. H_2O	3.2 in. H_2O	2770 ppm	1935 ppm	70%
MN-14	"	"	"	2.92	540°F	500°F	490°F	3.1 in. H_2O	3.9 in. H_2O	2740 ppm	2010 ppm	73%
AA-1R	Alkalized Alumina	30 min.	290 cfm	0.89	360°F	340°F	330°F	2.3 in. H_2O	3.2 in. H_2O	2795 ppm	1800 ppm	64%
AA-3R	"	"	"	0.78	320°F	315°F	315°F	2.2 in. H_2O	2.9 in. H_2O	2785 ppm	1800 ppm	64%
AA-4	"	"	"	0.74	410°F	400°F	380°F	1.6 in. H_2O	1.9 in. H_2O	2720 ppm	1590 ppm	58%
AA-5	"	"	"	0.81	510°F	500°F	460°F	2.0 in. H_2O	2.4 in. H_2O	2750 ppm	1235 ppm	45%
AA-6	"	"	"	0.75	515°F	500°F	470°F	1.9 in. H_2O	2.3 in. H_2O	2715 ppm	1300 ppm	48%
NH-1	Nahcolite	60 min.	290 cfm	0.77	295°F	300°F	325°F	0.3 in. H_2O	0.4 in. H_2O	2810 ppm	1660 ppm	59%

FLUE GAS FLOW RATE STUDY

Test Designation	Reactant Used	Test Interval	Gas Flow Rate	Stoich. Ratio	Bag Temperature			Pressure Drop		SO_2 Conc.		Average SO_2 Removal Over Interval
					Bottom	Middle	Top	Average	Final	To Bags	Removed From Flue Gases	
PL-1F	Slaked Lime (1% NaCl)	60 min.	385 cfm	2.01	955°F	915°F	835°F	4.1 in. H_2O	6.3 in. H_2O	2750 ppm	1400 ppm	51%
PL-2F	"	50 min.	385 cfm	1.77	955°F	900°F	835°F	6.9 in. H_2O	8.1 in. H_2O	2750 ppm	1290 ppm	47%
PL-3F	"	48 min.	385 cfm	1.24	980°F	905°F	840°F	9.1 in. H_2O	10+ in. H_2O	2735 ppm	1420 ppm	52%
PL-4F	"	42 min.	385 cfm	1.65	970°F	910°F	845°F	6.5 in. H_2O	9.0 in. H_2O	2745 ppm	1650 ppm	60%
PL-5F	"	60 min.	385 cfm	1.63	860°F	795°F	755°F	5.9 in. H_2O	8.0 in. H_2O	2770 ppm	1515 ppm	55%
PL-6F	"	60 min.	385 cfm	1.75	880°F	810°F	765°F	7.0 in. H_2O	9.1 in. H_2O	2750 ppm	1810 ppm	66%
PL-7F	"	48 min.	385 cfm	1.95	850°F	800°F	745°F	6.1 in. H_2O	8.9 in. H_2O	2750 ppm	2030 ppm	72%
PL-8F	"	52 min.	385 cfm	1.64	870°F	805°F	765°F	7.0 in. H_2O	9.7 in. H_2O	2740 ppm	1950 ppm	71%
PL-9F	"	42 min.	385 cfm	1.50	750°F	710°F	675°F	6.1 in. H_2O	8.4 in. H_2O	2750 ppm	1435 ppm	52%
MN-1F	Manganese Dioxide	60 min.	385 cfm	2.53	735°F	710°F	650°F	2.0 in. H_2O	3.1 in. H_2O	2745 ppm	1820 ppm	66%
MN-2F	"	60 min.	385 cfm	1.93	720°F	695°F	645°F	3.4 in. H_2O	4.3 in. H_2O	2700 ppm	1485 ppm	55%
MN-3F	"	60 min.	385 cfm	3.06	730°F	700°F	650°F	5.3 in. H_2O	7.0 in. H_2O	2770 ppm	2050 ppm	74%
MN-4F	"	60 min.	385 cfm	2.37	725°F	695°F	650°F	6.0 in. H_2O	7.7 in. H_2O	2770 ppm	1960 ppm	71%
MN-5F	"	60 min.	385 cfm	1.88	630°F	605°F	575°F	6.2 in. H_2O	7.4 in. H_2O	2760 ppm	1450 ppm	53%
MN-6F	"	60 min.	385 cfm	1.92	625°F	595°F	570°F	7.7 in. H_2O	8.7 in. H_2O	2770 ppm	1590 ppm	57%
MN-7F	"	60 min.	385 cfm	2.63	630°F	600°F	570°F	8.6 in. H_2O	10.0 in. H_2O	2780 ppm	2010 ppm	72%
MN-8F	"	60 min.	385 cfm	3.32	630°F	600°F	575°F	8.7 in. H_2O	10.5 in. H_2O	2775 ppm	2035 ppm	73%

FLUE GAS FLOW RATE STUDY

Test Designation	Reactant Used	Test Interval	Gas Flow Rate	Stoich. Ratio	Bag Temperature			Pressure Drop		SO_2 Conc.		Average SO_2 Removal Over Interval
					Bottom	Middle	Top	Average	Final	To Bags	Removed From Flue Gases	
MN-9F	Manganese Dioxide	60 min.	385 cfm	2.19	530°F	510°F	500°F	8.0 in. H_2O	9.4 in. H_2O	2775 ppm	1805 ppm	65%
MN-10F	"	40 min.	385 cfm	2.59	540°F	515°F	495°F	5.0 in. H_2O	6.4 in. H_2O	2765 ppm	1630 ppm	59%
MN-11F	"	60 min.	385 cfm	2.88	510°F	490°F	480°F	5.8 in. H_2O	7.5 in. H_2O	2765 ppm	1860 ppm	67%
MN-12F	"	60 min.	385 cfm	3.08	520°F	500°F	485°F	6.6 in. H_2O	8.4 in. H_2O	2750 ppm	1920 ppm	70%
UPL-3F	Slaked Lime	60 min.	385 cfm	2.16	1005°F	920°F	820°F	4.6 in. H_2O	5.5 in. H_2O	2790 ppm	1890 ppm	68%
UPL-4F	"	60 min.	385 cfm	1.99	1000°F	910°F	815°F	4.5 in. H_2O	5.7 in. H_2O	2720 ppm	1655 ppm	61%
UPL-5F	"	60 min.	385 cfm	2.81	1010°F	905°F	810°F	4.5 in. H_2O	6.0 in. H_2O	2750 ppm	2260 ppm	82%
UPL-6F	"	60 min.	385 cfm	3.39	1010°F	915°F	835°F	6.3 in. H_2O	7.6 in. H_2O	2735 ppm	2305 ppm	84%
UPL-7F	"	60 min.	385 cfm	2.03	880°F	800°F	730°F	4.8 in. H_2O	5.7 in. H_2O	2800 ppm	2240 ppm	80%
UPL-8F	"	60 min.	385 cfm	1.87	890°F	795°F	735°F	6.0 in. H_2O	7.3 in. H_2O	2730 ppm	2230 ppm	82%
UPL-9F	"	60 min.	385 cfm	2.98	920°F	810°F	745°F	6.6 in. H_2O	8.6 in. H_2O	2760 ppm	2440 ppm	88%
UPL-10F	"	50 min.	385 cfm	2.67	875°F	805°F	740°F	5.9 in. H_2O	6.9 in. H_2O	2760 ppm	2450 ppm	89%
UPL-11F	"	60 min.	385 cfm	2.06	755°F	710°F	670°F	5.5 in. H_2O	6.4 in. H_2O	2790 ppm	1610 ppm	58%
UPL-12F	"	60 min.	385 cfm	1.97	750°F	710°F	670°F	5.1 in. H_2O	6.6 in. H_2O	2740 ppm	1430 ppm	52%
UPL-13F	"	60 min.	385 cfm	2.82	740°F	700°F	680°F	6.1 in. H_2O	8.2 in. H_2O	2735 ppm	1980 ppm	72%
UPL-14F	"	60 min.	385 cfm	2.85	750°F	705°F	670°F	6.5 in. H_2O	8.2 in. H_2O	2760 ppm	2010 ppm	73%
NH-2F	Nahcolite	60 min.	610 cfm	0.66	330°F	320°F	335°F	1.4 in. H_2O	2.1 in. H_2O	2830 ppm	1700 ppm	60%
NH-3F	"	60 min.	685 cfm	0.67	520°F	520°F	510°F	2.3 in. H_2O	3.6 in. H_2O	2830 ppm	1670 ppm	59%

FLUE GAS FLOW RATE STUDY

Test Designation	Reactant Used	Test Interval	Gas Flow Rate	Stoich. Ratio	Bag Temperature			Pressure Drop		SO_2 Conc.		Average SO_2 Removal Over Interval
					Bottom	Middle	Top	Average	Final	To Bags	Removed From Flue Gases	
PD-1F	Slaked Dolomitic Lime (1% NaCl)	60 min.	385 cfm	2.31	950°F	910°F	845°F	3.9 in. H_2O	6.0 in. H_2O	2750 ppm	1755 ppm	64%
PD-2F	"	60 min.	385 cfm	1.53	950°F	900°F	840°F	6.1 in. H_2O	8.3 in. H_2O	2720 ppm	1485 ppm	55%
PD-3F	"	60 min.	385 cfm	2.04	855°F	800°F	755°F	6.7 in. H_2O	8.8 in. H_2O	2760 ppm	1600 ppm	58%
PD-4F	"	60 min.	385 cfm	2.19	855°F	800°F	740°F	5.6 in. H_2O	7.8 in. H_2O	2775 ppm	1605 ppm	58%
PD-5F	"	60 min.	385 cfm	2.24	745°F	700°F	675°F	5.6 in. H_2O	9.8 in. H_2O	2800 ppm	1310 ppm	47%
PD-6F	"	60 min.	385 cfm	1.96	740°F	700°F	680°F	5.9 in. H_2O	9.4 in. H_2O	2740 ppm	1190 ppm	43%
PD-7F	"	60 min.	385 cfm	3.31	940°F	910°F	850°F	10.+ in. H_2O	10.+ in. H_2O	2740 ppm	1950 ppm	71%
PD-8F	"	60 min.	385 cfm	3.12	970°F	890°F	810°F	6.5 in. H_2O	8.2 in. H_2O	2760 ppm	1870 ppm	68%
PD-9F	"	48 min.	385 cfm	3.24	865°F	810°F	765°F	7.3 in. H_2O	9.9 in. H_2O	2720 ppm	2075 ppm	76%
PD-10F	"	40 min.	385 cfm	3.20	855°F	810°F	770°F	7.0 in. H_2O	10.0 in. H_2O	2735 ppm	2060 ppm	75%
PD-11F	"	60 min.	385 cfm	3.37	740°F	700°F	685°F	6.5 in. H_2O	9.7 in. H_2O	2700 ppm	1690 ppm	63%
PD-12F	"	60 min.	385 cfm	3.24	735°F	695°F	665°F	5.1 in. H_2O	8.2 in. H_2O	2775 ppm	1815 ppm	65%
SD-1F	Slaked Dolomitic Lime	60 min.	385 cfm	2.13	960°F	900°F	840°F	2.6 in. H_2O	3.8 in. H_2O	2775 ppm	1305 ppm	47%
SD-2F	"	60 min.	385 cfm	1.85	860°F	890°F	825°F	3.3 in. H_2O	4.3 in. H_2O	2725 ppm	950 ppm	35%
SD-3F	"	60 min.	385 cfm	1.61	855°F	800°F	750°F	4.1 in. H_2O	5.5 in. H_2O	2740 ppm	1350 ppm	49%
SD-4F	"	60 min.	385 cfm	1.92	840°F	795°F	750°F	3.5 in. H_2O	4.8 in. H_2O	2775 ppm	1455 ppm	52%
SD-5F	"	60 min.	385 cfm	1.97	740°F	695°F	670°F	3.4 in. H_2O	4.5 in. H_2O	2775 ppm	1155 ppm	40%

FLUE GAS FLOW RATE STUDY

Test Designation	Reactant Used	Test Interval	Gas Flow Rate	Stoich. Ratio	Bag Temperature			Pressure Drop		SO_2 Conc.		Average SO_2 Removal Over Interval
					Bottom	Middle	Top	Average	Final	To Bags	Removed From Flue Gases	
SD-6F	Slaked Dolomitic Lime	60 min.	385 cfm	1.98	740°F	700°F	670°F	4.3 in. H_2O	6.0 in. H_2O	2780 ppm	1120 ppm	40%
SD-7F	"	60 min.	385 cfm	2.77	945°F	895°F	835°F	4.9 in. H_2O	6.7 in. H_2O	2740 ppm	1460 ppm	53%
SD-8F	"	60 min.	385 cfm	2.83	960°F	895°F	820°F	4.1 in. H_2O	5.3 in. H_2O	2740 ppm	1480 ppm	54%
SD-9F	"	60 min.	385 cfm	2.87	940°F	885°F	815°F	5.7 in. H_2O	7.6 in. H_2O	2760 ppm	1760 ppm	64%
SD-10F	"	60 min.	385 cfm	2.94	850°F	795°F	745°F	3.7 in. H_2O	4.6 in. H_2O	2760 ppm	1930 ppm	71%
SD-11F	"	60 min.	385 cfm	3.07	845°F	795°F	740°F	5.6 in. H_2O	7.5 in. H_2O	2760 ppm	1930 ppm	70%
SD-12F	"	48 min.	385 cfm	3.02	740°F	695°F	670°F	6.2 in. H_2O	8.0 in. H_2O	2725 ppm	1495 ppm	55%
SD-13F	"	60 min.	385 cfm	3.21	730°F	700°F	680°F	2.9 in. H_2O	4.5 in. H_2O	2720 ppm	1410 ppm	52%
SD-17F	"	60 min.	385 cfm	2.38	960°F	900°F	835°F	1.6 in. H_2O	2.3 in. H_2O	2760 ppm	1885 ppm	68%
SD-18F	"	60 min.	385 cfm	1.75	840°F	805°F	760°F	2.1 in. H_2O	3.2 in. H_2O	2775 ppm	1595 ppm	57%
SD-19F	"	60 min.	385 cfm	1.79	840°F	810°F	760°F	3.3 in. H_2O	4.4 in. H_2O	2425 ppm	1500 ppm	62%
AA-1F	Alkalized Alumina	30 min.	385 cfm	0.64	365°F	355°F	335°F	.9 in. H_2O	1.2 in. H_2O	2775 ppm	1590 ppm	57%
AA-2F	"	"	385 cfm	0.57	350°F	345°F	335°F	2.5 in. H_2O	2.8 in. H_2O	2750 ppm	1545 ppm	56%
AA-3F	"	"	385 cfm	0.52	315°F	315°F	295°F	1.9 in. H_2O	2.4 in. H_2O	2800 ppm	1335 ppm	48%
AA-7F	"	"	385 cfm	0.77	520°F	510°F	480°F	3.0 in. H_2O	3.7 in. H_2O	2740 ppm	1450 ppm	53%
AA-8F	"	"	385 cfm	0.77	525°F	515°F	485°F	2.2 in. H_2O	3.0 in. H_2O	2735 ppm	1505 ppm	55%
AA-9F	"	"	385 cfm	0.60	525°F	515°F	495°F	3.0 in. H_2O	4.0 in. H_2O	2820 ppm	1560 ppm	55%
AA-10F	"	"	385 cfm	0.58	415°F	410°F	395°F	3.7 in. H_2O	4.5 in. H_2O	2800 ppm	1510 ppm	54%
AA-11F	"	"	385 cfm	0.60	335°F	335°F	315°F	2.1 in. H_2O	2.9 in. H_2O	2790 ppm	1550 ppm	56%
AA-12F	"	"	385 cfm	0.66	340°F	330°F	315°F	1.9 in. H_2O	2.4 in. H_2O	2775 ppm	1850 ppm	67%

BAG COATING STUDY

Test Designation	Reactant Used	Test Interval	Gas Flow Rate	Stoich. Ratio	Bag Temperature			Pressure Drop		SO_2 Conc.		Average SO_2 Removal Over Interval
					Bottom	Middle	Top	Average	Final	To Bags	Removed From Flue Gases	
UPL-1FB	Slaked Lime	60 min.	385 cfm	2.28	705°F	690°F	675°F	8.1 in. H_2O	9.6 in. H_2O	2775 ppm	775 ppm	28%
UPL-2FB	"	"	385 cfm.	2.19	835°F	785°F	750°F	5.2 in. H_2O	8.8 in. H_2O	2700 ppm	1480 ppm	55%
UPL-3FB	"	"	385 cfm	2.12	835°F	800°F	755°F	8.5 in. H_2O	8.5 in. H_2O	2725 ppm	925 ppm	33%
UPL-4FB	"	"	385 cfm	2.09	995°F	900°F	825°F	8.2 in. H_2O	8.3 in. H_2O	2750 ppm	740 ppm	27%
UPL-5FB	"	"	385 cfm	1.80	990°F	900°F	830°F	8.8 in. H_2O	9.6 in. H_2O	2740 ppm	840 ppm	31%
MN-1FB	Manganese Dioxide	"	385 cfm	3.36	635°F	600°F	555°F	2.6 in. H_2O	2.5 in. H_2O	2800 ppm	2530 ppm	90%
MN-2FB	"	"	385 cfm	3.35	635°F	600°F	580°F	5.7 in. H_2O	5.4 in. H_2O	2820 ppm	2500 ppm	89%
MN-3FB	"	"	385 cfm	3.49	755°F	700°F	670°F	9.3 in. H_2O	9.3 in. H_2O	2750 ppm	2430 ppm	88%
MN-4FB	"	"	385 cfm	3.47	735°F	695°F	655°F	8.8 in. H_2O	8.7 in. H_2O	2760 ppm	2480 ppm	90%
MN-5FB	"	"	385 cfm	2.91	535°F	505°F	500°F	No data --	off scale	2770 ppm	2230 ppm	80%
MN-6FB	"	"	385 cfm	1.74	535°F	500°F	505°F	10.0 in. H_2O	9.9 in. H_2O	2750 ppm	1935 ppm	70%
MN-7FB	"	"	385 cfm	2.20	655°F	600°F	595°F	No data --	off scale	2750 ppm	2205 ppm	80%
MN-8FB	"	"	385 cfm	2.35	760°F	700°F	680°F	No data --	off scale	2760 ppm	2290 ppm	83%
MN-9B	"	"	290 cfm	1.96	690°F	610°F	590°F	9.0 in. H_2O	8.9 in. H_2O	2760 ppm	1280 ppm	46%
MN-10B	"	"	290 cfm	2.30	800°F	710°F	675°F	9.4 in. H_2O	9.2 in. H_2O	2760 ppm	1530 ppm	55%

FLY ASH STUDY

Test Designation	Reactant Used	Test Interval	Gas Flow Rate	Stoich. Ratio	Bag Temperature			Pressure Drop		SO_2 Conc.		Average SO_2 Removal Over Interval
					Bottom	Middle	Top	Average	Final	To Bags	Removed From Flue Gases	
UPL-FA-1F	Slaked Lime	60 min.	385 cfm	1.99	810°F	785°F	725°F	2.9 in. H_2O	5.1 in. H_2O	2750 ppm	2135 ppm	78%
UPL-FA-2F	"	"	385 cfm	2.02	815°F	790°F	740°F	3.2 in. H_2O	4.4 in. H_2O	2750 ppm	2320 ppm	85%
FD-FA-1F	Slaked Dolomitic Lime (1% NaCl)	"	385 cfm	1.89	850°F	800°F	750°F	4.2 in. H_2O	6.3 in. H_2O	2740 ppm	1645 ppm	60%
FD-FA-2F	"	"	385 cfm	1.99	860°F	800°F	730°F	3.0 in. H_2O	4.9 in. H_2O	2740 ppm	1910 ppm	70%
FL-FA-1F	Slaked Lime (1% NaCl)	"	385 cfm	2.02	875°F	825°F	765°F	4.7 in. H_2O	7.9 in. H_2O	2750 ppm	2035 ppm	74%
FL-FA-2F	"	"	385 cfm	1.96	835°F	795°F	750°F	4.2 in. H_2O	7.4 in. H_2O	2740 ppm	2010 ppm	73%
SD-FA-1F	Slaked Dolomitic Lime	"	385 cfm	1.95	840°F	805°F	765°F	4.7 in. H_2O	8.0 in. H_2O	2750 ppm	1360 ppm	50%
SD-FA-2F	"	"	385 cfm	2.08	830°F	800°F	750°F	4.0 in. H_2O	5.8 in. H_2O	2725 ppm	1525 ppm	56%
MN-FA-1F	Manganese Dioxide	"	385 cfm	2.16	680°F	640°F	610°F	4.5 in. H_2O	7.0 in. H_2O	2740 ppm	2160 ppm	79%

APPENDIX D

Sulfur Analysis

Sulfur Content of Fallout and Dustcake Samples

From Representative Tests*

I Additive Study

Sample Description	% SO_4	% SO_3	% Total Sulfur
UPL-9 Fallout	8.55	12.15	7.72
UPL-9 Dustcake	6.44	10.95	6.54
UPL-13 Fallout	12.09	11.90	8.81
UPL-13 Dustcake	14.12	12.90	9.88
UPL-15 Fallout	11.72	9.45	7.70
UPL-15 Dustcake	16.37	15.70	11.76
UPL-17 Fallout	11.10	10.05	7.73
UPL-17 Dustcake	12.06	10.60	8.27
UPL-18 Fallout	7.67	10.65	6.83
UPL-18 Dustcake	11.83	12.00	8.76
UPL-19 Fallout	5.69	12.00	6.71
UPL-19 Dustcake	5.05	10.55	5.91
UPL-22 Fallout	5.57	12.35	6.81
UPL-22 Dustcake			
SD-4 Fallout	8.38	6.75	5.50
SD-4 Dustcake	11.71	12.87	9.07
SD-14 Fallout	5.71	6.75	4.61
SD-14 Dustcake	11.40	8.35	7.15
SD-15 Fallout	8.08	12.10	7.55
SD-15 Dustcake	6.77	7.47	5.25
PD-8 Fallout	12.09	4.20	5.72
PD-8 Dustcake	17.89	8.75	9.48
PD-11 Fallout	8.63	7.40	5.85
PD-11 Dustcake	25.24	9.85	12.37
PD-18 Fallout	32.41	2.37	11.77
PD-18 Dustcake	20.69	2.50	7.91
AA-4 Fallout	24.63	1.25	8.73
AA-4 Dustcake	29.81	1.00	10.35

*Samples analyzed by Gilbert Associations, Inc. , Reading, Pennsylvania

I Additive Study (Continued)

Sample Description	% SO_4	% SO_3	% Total Sulfur
PL-5 Fallout	9.75	9.40	7.02
PL-5 Dustcake	13.02	12.35	9.30
PL-6 Fallout	5.23	11.90	6.52
PL-6 Dustcake	8.41	12.95	8.00
PL-13 Fallout	2.08	5.45	2.88
PL-13 Dustcake	24.41	6.75	10.85

II Flue Gas Flow Rate Study

Sample Description	% SO_4	% SO_3	% Total Sulfur
SD-2F Fallout	8.02	6.90	5.44
SD-2F Dustcake	16.97	9.90	9.63
SD-3F Fallout	5.39	8.15	5.07
SD-3F Dustcake	15.93	13.45	10.71
SD-5F Fallout	11.07	9.45	7.48
SD-5F Dustcake	11.79	9.00	7.54
SD-6F Fallout	8.77	8.15	6.20
SD-6F Dustcake	11.56	13.65	9.33
SD-8F Fallout	8.72	6.95	5.70
SD-8F Dustcake	13.26	6.95	7.21
SD-9F Fallout	12.10	8.05	7.27
SD-9F Dustcake	14.13	12.00	9.53
SD-10F Fallout	10.13	6.80	6.11
SD-10F Dustcake	12.81	11.45	8.87
SD-11F Fallout	4.96	7.70	4.74
SD-11F Dustcake	12.22	8.40	7.44
SD-12F Fallout	8.15	7.15	5.59
SD-12F Dustcake	12.69	14.75	10.15
SD-13F Fallout	5.32	7.60	4.82
SD-13F Dustcake	8.14	10.25	6.82

II Flue Gas Flow Rate Study (Continued)

Sample Description	% SO_4	% SO_3	% Total Sulfur
PD-1F Fallout	13.18	4.30	6.12
PD-1F Dustcake	35.01	3.30	13.01
PD-3F Fallout	11.25	7.30	6.68
PD-3F Dustcake	34.28	5.80	13.77
PD-4F Fallout	11.17	6.70	6.41
PD-4F Dustcake	32.74	2.55	11.96
PD-5F Fallout	5.24	5.20	3.83
PD-5F Dustcake	24.33	7.45	11.11
PD-7F Fallout	12.98	2.95	5.52
PD-7F Dustcake	27.51	4.05	10.81
PD-10F Fallout	10.35	5.95	5.84
PD-10F Dustcake	29.70	4.65	11.78
PD-12F Fallout	7.76	7.00	5.40
PD-12F Dustcake	14.49	8.05	8.06
MN-2F Fallout	16.22	0.30	5.54
MN-2F Dustcake	21.50	0.65	7.44
MN-8F Fallout	18.59	0.35	6.35
MN-8F Dustcake	25.79	0.40	8.77
UPL-3F Fallout	14.38	14.30	10.53
UPL-3F Dustcake	20.63	9.85	10.84
UPL-10F Fallout	8.22	13.80	8.27
UPL-10F Dustcake	13.55	7.15	7.39
UPL-14F Fallout	2.48	13.35	6.18
UPL-14F Dustcake	7.12	14.70	8.24
AA-1F Fallout	25.03	1.15	8.82
AA-1F Dustcake	31.59	0.70	10.83
AA-8F Fallout	19.77	3.50	9.38
AA-8F Dustcake	23.84	2.25	8.86
AA-10F Fallout	27.94	0.84	9.67
AA-10F Dustcake	32.36	0.55	11.03
AA-12F Fallout	27.55	0.95	9.58
AA-12F Dustcake	30.37	0.65	10.40

III Bag Coating Study

Sample Description	% SO_4	% SO_3	% Total Sulfur
MN-4FB Fallout	24.23	0.60	8.33
MN-4FB Dustcake	23.46	0.50	7.49
MN-5FB Fallout	25.96	0.35	8.81
MN-5FB Dustcake	25.81	0.50	8.82
MN-10B Fallout	27.30	0.40	9.27
MN-10B Dustcake	26.26	0.60	9.01

IV Fly Ash Study

Sample Description	% SO_4	% SO_3	% Total Sulfur
UPL-FA-1F Fallout	5.38	8.65	5.26
UPL-FA-1F Dustcake	9.76	7.90	6.42
SD-FA-1F Fallout	8.23	6.45	5.33
SD-FA-1F Dustcake	5.73	8.50	5.32
PL-FA-1F Fallout	3.62	7.10	4.05
PL-FA-1F Dustcake	5.98	13.50	7.41
PD-FA-2F Fallout	5.39	4.45	3.58
PD-FA-2F Dustcake	4.19	4.50	3.20
MN-FA-1F Fallout	11.59	1.50	4.47

APPENDIX E

Physical Properties of Reactants

Reactant Physical Properties

		B.E.T. Surface Area* M^2/gram	Density grams/cm^3	Measured Pore Volume* cm^3/gm	Coulter Counter Particle Size + Microns-Wt. Basis	
					MEAN	MAXIMUM
1.	Slaked Lime	9.1	3.03	1.09	6.0	19.0
2.	Slaked Dolomite Lime	9.5	3.28	1.00	6.8	24.0
3.	Slaked Dolomite Lime (1% NaCl)	6.9	3.33	0.97	9.0	24.0
4.	Slaked Lime (1% NaCl)	18.6	2.70	0.93	6.4	19.0
5.	Manganese Dioxide	42.5	5.32	0.63	14	30.0
6.	Alkalized Alumina	114.3	1.80	1.38	24	48.0
7.	Nahcolite	6.1	2.53	0.63	13	38.0

*Determined by American Instrument Company, Silver Springs, Md.

+Determined at NAPCA Laboratories, Cincinnati, Ohio

APPENDIX F

Coulter Counter Particle Size Analysis of Reaction Products

Coulter Counter Particle Size Analysis * of Reaction Products

Test Designation	Particle Diameter - Microns			
	Dustcake		Fallout	
	Mean	Maximum	Mean	Maximum
MN -2	19	38	8.0	19
MN -5	15	31	8.2	19
NH-1	20	38	19	38
NH-4	19	38	11	30
UPL-9	10	24	10	24
UPL-17	12	24	16	30
UPL-22	14	30	12	30
SD-4	9.6	24	7.6	24
SD-11	7.8	24	9.4	24
PD-11	10	24	6.4	19
PD-18	8.6	24	10.5	24
PL-6	11	24	10.5	24
PL-13	15	30	14	30

* Determined at NAPCA Laboratories, Cincinnati, Ohio.

APPENDIX G

Carbonate Analyses of Lime-Based Reaction Products

Carbonate Analyses of Lime-Based Reaction Products

	Wt. % Carbon Dioxide	
Run No.	Fallout	Dustcake
SD - 4	8.9	9.5
SD - 14	10.9	10.6
SD - 15	8.3	10.4
SD - 12	11.3	8.4
SD - 2F	7.2	10.5
SD - 8F	13.4	10.1
PD - 1	9.5	4.7
PD - 10	12.8	7.9
PD - 8	6.3	5.7
PD - 18	8.1	9.1
PD - 11	10.7	7.2
PL - 5	14.5	12.3
PL - 13	24.1	16.8
PL - 6	13.6	12.9
UPL- 9	11.0	11.3
UPL- 13	13.9	8.1
UPL- 15	11.2	11.9
UPL- 19	11.2	12.9
UPL- 22	15.3	12.3